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Linda Bussell EdD
University of San Diego

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THE EFFECT OF FORCE FEEDBACK ON STUDENT REASONING ABOUT GRAVITY, MASS, FORCE AND MOTION

by

Linda Bussell

A dissertation submitted to the faculty of
San Diego State University and the University of San Diego
in partial fulfillment of the requirements for the degree of
Doctor of Education

Dissertation Committee:

Susan M. Zgliczynski, Ph.D, USD
Bob Hoffman, Ph.D, SDSU
Cheryl L. Mason, Ph.D, SDSU

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Abstract

The purpose of this study was to examine whether force feedback within a computer simulation had an effect on reasoning by fifth grade students about gravity, mass, force, and motion, concepts which can be difficult for learners to grasp. Few studies have been done on cognitive learning and haptic feedback, particularly with young learners, but there is an extensive base of literature on children's conceptions of science and a number of studies focus specifically on children's conceptions of force and motion.

This case study used a computer-based paddleball simulation with guided inquiry as the primary stimulus. Within the simulation, the learner could adjust the mass of the ball and the gravitational force. The experimental group used the simulation with visual and force feedback; the control group used the simulation with visual feedback but without force feedback. The proposition was that there would be differences in reasoning between the experimental and control groups, with force feedback being helpful with concepts that are more obvious when felt.

Participants were 34 fifth-grade students from three schools. Students completed a modal (visual, auditory, and haptic) learning preference assessment and a pretest. The sessions, including participant experimentation and interviews, were audio recorded and observed. The interviews were followed by a written posttest. These data were analyzed to determine whether there were differences based on treatment, learning style, demographics, prior gaming experience, force feedback experience, or prior knowledge.

Work with the simulation, regardless of group, was found to increase students' understanding of key concepts. The experimental group appeared to benefit from the supplementary help that force feedback provided. Those in the experimental group scored higher on the posttest than those in the control group. The greatest difference between mean group scores was on a question concerning the effects of increased gravitational force.

Dedication

To the memory of my mother, Shirley D. Clow, who has been a motivating force through her love of learning and belief in the value of education. Her influence continues to inspire me.

And to my husband, Rick Bussell, who has continually encouraged and supported me on this long, long journey.

Acknowledgements

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Ilse Ortabasi has given me enormous support and encouragement over the years. I know she has been inconvenienced many times when my school schedule impinged on my work schedule. She has served as a sounding board for emerging ideas and frustrations. Ilse assisted with data coding and she reviewed the draft and offered valuable feedback. Rick Bussell, Jim Clow, and Maria Grant have reviewed the dissertation and provided helpful comments and suggestions. Thanks to all.

Thanks to Cohort 1 for being there as we went through this together, for listening and supporting me and letting me know that I was not alone when it felt that way sometimes. Finally, thanks to my family and friends for their understanding over the past years. Without your support, this would not have been possible.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Science literacy among American students is not what it should be. Based on findings from the Third International Mathematics and Science Study (TIMSS), U.S. fourth graders' scores ranked second in science achievement among participating nations. That was the end of the good news. U.S. student performance declined between grades four and eight in relation to that of other nations. By the twelfth grade, science performance for U.S. students was below average, and physics performance was particularly low (Stevenson, 1998; Greene, Herman, & Haury). The news is even more dismal for girls. Girls and boys at the fourth grade level performed equally, but girls' performance in relation to boys' performance declined between grades four and eight, and continued to decline between grades eight and twelve (Stevenson, 1998; Greene et al.).

In *Science for All Americans*, the Association for the Advancement of Science (1989) states that most Americans cannot be considered scientifically literate. This has national and global implications as people are called upon every day to make informed decisions about science and technology issues that they are not adequately prepared to comprehend. As a nation with vast resources and a leadership role in science and technology, clearly we need to do better.

Research Problem and Significance

Though still in its early stages, haptic feedback technology has shown promise as a means to convey concepts of physical science to undergraduates. To date, most educational applications of haptic technology have been focused on creating more realistic virtual experiences of procedures that have a significant psychomotor component. Examples include medical and dental procedures (e.g., laparoscopy, vascular access, drilling and restoration) and flight simulation training. In applications such as these, students need to make judgments by determining through haptic feedback how much force to apply, and under what conditions, to achieve a desired effect.

Because haptic technology is relatively new, extant research on simulated haptic feedback and cognitive learning is sparse, particularly as it applies to children. For instance, no study could be found that examined what effect haptic feedback within a simulation may have on children's reasoning about force and motion, a notoriously difficult content area. Conducting a study in which children attempted to come to a basic understanding of force concepts through an experience of simulated force feedback seemed a natural and potentially useful extension of the work that has been done with other populations.

This study examined the effect of haptic feedback within a computer simulation on children's reasoning about gravity, mass, force, and motion. The treatment group used the simulation with both visual and haptic feedback. The control group used the same simulation, but with visual feedback only. Qualitative and quantitative data were collected, coded and analyzed.

Subjects completed a modal learning preference assessment and a survey regarding prior experience with the science concepts, force feedback, and video games prior to being assigned to groups. Subjects were assigned to groups on the basis of modal learning preference and gender. Beyond the main research questions, this study looked for effects related to learning mode preference, gender, and prior experiences.

This study investigated these questions with the goal of contributing to the body of research in haptic technology and cognitive learning, with particular application for elementary science education. The results of this study may provide useful information or guidelines for educational software designers to apply to the design of more effective learning environments for children.

Overview of the Literature Review and Theoretical Perspectives

Haptic computer input/output devices provide force and/or tactile feedback to the user. Consumer haptic devices such as joysticks, wheels, and mice for personal computers have been in existence for several years, and are mostly marketed for use with entertainment games. Relatively little research has been done with haptic computer interfaces compared with typical graphical user interfaces. In particular, little research has been conducted regarding the application of haptic technology to educational purposes that do not have an essential psychomotor aspect. Mainstream educational or edutainment titles such as *Zoombinis Logical Journey*™ that employ haptic feedback have done so primarily to boost the entertainment value rather than the educational effectiveness of the product. And yet, research has shown that nonessential visual and auditory stimuli negatively impact learning (Mayer, 2001). The same could be true for non-essential haptic stimuli.

Existing research has shown that performance can be improved with haptic feedback as evidenced by quicker response times and fewer errors (e.g., (Burdea, 1996; Richard et al., 1996; Sallnäs, 2000). Haptic feedback has been used effectively for specialized applications such as surgical simulators that have a critical tactile or kinesthetic aspect. Some research has been done in the area of haptic computer interfaces for visually impaired learners with some promising results both as an adaptive technology and as an educational tool for math and science education (e.g., Van Scoy, Kawai, Darrah, & Rash, 2000; Wies, Gardner, O'Modhrain, Hasser, & Bulatov, 2000). Some research with haptic learning environments has been done in the physics domain with college students to teach content related to forces and electrical fields (Reiner, 1999; Wies et al., 2000). Perhaps haptic feedback can help to promote the development of scientific concepts in younger students as well.

Much is known about how visual and verbal information is processed. For instance, dual coding theory (Paivio, 1986) tells us that memory can be enhanced if both nonverbal and verbal channels are employed in instruction. However, an overload of information in one channel may interfere with cognitive processing (Mayer, 2001). Can memory be enhanced if the haptic sensory mode is employed along with the visual mode, or is memory hindered due to interference with visual stimuli in the nonverbal channel? If the non-visual information is not identical to the visual but is conveying information (e.g., changes in gravity or mass) through direct sensory experience rather than through secondary visual evidence, will this interfere with or enhance processing? In other words, is the channel constraint verbal/nonverbal or is it sensory-based?

Rationale for the Study

At this time, scant research has been done on the subject of haptic interfaces for educational purposes. The technology is in its infancy, and now is the time to begin investigating how it can be used effectively, before quantities of time, money and effort are expended on implementations that do not work, or even worse, have a detrimental effect. Guiding principles need to be developed with regard to educational applications, motivational factors, and implementation strategies. Since the relevant literature is scarce, an exploratory study seemed appropriate to guide future research and application.

Elementary physical science education was selected as a content area for a number of reasons. First, some of the related research with other populations has used physical science as a content area with promising results. Second, the technology seemed a natural extension of the content; after all, force feedback conveys forces. Third, a suitable simulation was available for use. And finally, an innovative technology solution could perhaps help learners to develop a better understanding of these difficult concepts.

Goals of This Study

The primary goal of this study was to investigate the effects of force feedback on students' reasoning about gravity, mass, force, and motion. This study adds to the limited body of research on computer-based haptic technology with application to elementary science education. The findings provide information to help guide future software design and research efforts.

Audiences for the Research Findings

The findings of this study may prove useful to science educators and instructional designers. It would be useful to know whether or not and in what ways haptic technology can offer an instructional edge in conveying difficult concepts. It would also be useful to know when haptic technology does not benefit learning, so that scarce resources and instructional efforts can be expended more productively. Where force feedback seems to help convey some concepts but not others, the feedback or accompanying materials and instruction can be designed so as to gainfully focus student attention.

Others who may benefit from the results of this study are educational software designers and developers. Force feedback is difficult and expensive to implement convincingly in a software program, often requiring the specialized knowledge of a physics expert to calculate the appropriate forces for a particular application. Where there is little or no beneficial effect, resources may be better allocated elsewhere. As is the case in other fields that employ haptic technology, potential benefits should be weighed against costs.

Manufacturers of haptic input devices may benefit from the results of the study, particularly if the results show a positive effect of haptic feedback. Currently, there is a dearth of affordable, effective haptic input devices, although there is a degree of consumer and researcher interest. If the technology proves to benefit learning, this would be a further motivation for current or future manufacturers to produce effective yet affordable products for school and home use.

Research Questions

The main research question that this study will address is: Does force feedback in a simulation have an effect on students' reasoning about concepts of gravity, mass, force, and/or motion? To answer this question, two questions that must be addressed are

Does the simulation in question (regardless of feedback modes) have an effect on learners' conceptions of key concepts?

Do differences exist between the reasoning of learners who practice with a simulation with visual and force feedback and those who practice with visual feedback only?

Sub-questions that will be addressed in this study are as follows: Is haptic feedback motivating (e.g., fun, novel) for the target population? Does the effectiveness of the treatment vary according to modal preference? Is force feedback more effective for learners who have a haptic preference? Is force feedback less effective for learners who have a visual preference? Is there a difference among subgroups based on the following factors: gender, socio-economic status, prior video game experience, prior force feedback experience, prior knowledge?

Limitations and Assumptions of the Study

As with all case study research, this study is situated and specific to the particular environment, treatment, and population. The researcher's perspective is reflected in the study, and the researcher's expectations may have inadvertently influenced the results. The interview results may have been affected by inadvertent cues from the interviewer. This study assumed that the participants considered the questions seriously and gave sincere, thoughtful responses.

The study included self-report and self-assessment data, which can be misleading. The subjects are at the lower age limit for which reliability data have been obtained for the instrument that was used to determine their modal preferences. The ability for individuals to reflect on their preferred mode of learning is developmental, and this may be a limitation of the study. Children at this age and grade are considered to be at the beginning stage of being able to reflect on their preferred mode of learning (O'Brien, personal communication, April 14, 2003).

Definitions of Terms

The following are definitions of terms as they are used within this study.

Haptic. The word haptic is derived from the Greek word for touch. It refers to the tactile and kinesthetic senses.

Force feedback. In computer technology, force feedback devices convey a sense of forces to the user. With force feedback, virtual objects can be made to feel solid, and the user can experience simulated force effects such as gravity and friction.

Learning styles. Learning styles refer to the unique combinations of strengths, weaknesses, and preferences with which people approach learning. Learning styles encompass aspects of cognition, perceptual and environmental preferences, and personality.

Modal preference. Modal preference refers to the perceptual mode or modes (visual, auditory, or haptic) that a learner prefers during learning.

These and other topics are discussed in greater detail in the next chapter.

Chapter 2: Review of the Literature

This study examined the impact of force feedback within a software simulation on students' reasoning about gravity, mass, force and motion. As noted in the previous chapter, there is little extant research on this topic. Therefore, this review of the literature focuses on literature related to various aspects of the research question: the importance of touch to cognition and learning; the acquisition of concepts of forces in young learners; theories of cognition that may shed light on the process of learning through multimedia simulations and force feedback; prior studies related to learning through computer simulation and haptic interfaces, and learning styles and modal preferences.

Sources for this literature review were located primarily through searching a variety of electronic databases available through libraries at San Diego State University, the University of California at San Diego, and the University of San Diego. Two primary databases employed in this search were ERIC and PsycINFO. Some of the subject headings searched were tactual perception, cognitive styles, science education, cognitive theories, cognitive load, and modal preferences, both alone and in various combinations, and among many others. I searched Dissertation Abstracts for dissertations related to learning through simulations and haptics, and the design of haptic interfaces for learning applications. Other reference materials came to my attention during coursework or by way of colleagues who were aware of my interests. Many of the references cited were available for download from the Internet, either directly or via article databases. Books and other articles were available through the libraries mentioned above; others were made available through the Interlibrary Loan service.

The remainder of this chapter will focus on a review and discussion of the evidence that force feedback in a simulation may hold promise for helping to make difficult concepts more accessible to learners.

The Importance of Touch to Cognition and Learning

Touch is critical for normal human development. Infants who do not receive sufficient touch contact fail to thrive physically, cognitively, or socially (Blackwell, 2000). As physical beings, we act upon and interact with our environment through force. We become aware of our world through interacting with it from the day we are born. As we strive to make sense of our experiences, our understanding of forces plays an essential role (Johnson, 1987; Piaget, 1970). As infants and young children we explore our world, developing schema for the patterns of forces that we encounter and attaching meaning to them. We develop a sense of balance first by learning to totter about on two legs, and eventually learning to run, dance and ride a bicycle. Later, we attach meaning to the word "balance" that we first experienced physically. Thus, our physical experience helps to shape our understanding of our language.

Much of our thinking is metaphorical and many of these metaphors have a spatial or force basis (Lakoff & Johnson, 1980, 1999). For example, we speak of grasping a concept, getting in over our heads, being bowled over or having a thought strike. Abstract concepts come to be understood in terms of more concrete concepts through the use of metaphor (Lakoff & Nuñez, 2000). Metaphorical thought and language help to shape children's conceptions about the world and can also contribute to misconceptions (Windschitl, 1995; Hart, 2002).

Our sense of touch helps us to form mental models of the shape and structure of objects. This is why we can recognize objects by touch alone. We learn much about how the world operates through direct experience, and through this experience our bodies become more aware of natural forces than our conscious minds do. We learn to hit a moving target such as a tennis ball by repeatedly trying until we are successful. Our muscles learn how much force to apply and in what direction to place the ball where we want. But, for all our expertise, this embodied knowledge is difficult to put into words. Embodied knowledge is implicit, tacit, and based on non-propositional structures of meaning (Reiner, 1999), so it is difficult to describe exactly what we are doing when we hit that ball to our opponent's weaker side. Implicit memory is automated, expertise gained through years of elaboration and practice under countless conditions (Anderson, 2000). Once, perhaps, we had to think through our movements at the direction of a coach or teacher. But when we have gained expertise we do not need to think about it anymore, and so the skill requires a low cognitive load. Implicit memory is an efficient use of cognitive resources, and since it is constructed of physical connections developed over time, these protein-based connections are fast and persistent.

Developing Understandings of Physical Science Concepts

Our embodied knowledge is essential to our successful day-to-day living. But our experiences can also impede later learning. Many science concepts run counter to our commonsense understanding of the world; this is one reason alternative conceptions of science can be persistent and difficult to dislodge, even after substantial efforts at instruction have been made. These commonsense ideas may continue to coexist with conflicting ideas that have been gained through science instruction, so that an individual may hold separate models for the real world and the science classroom. Since alternative conceptions tend to be formed early on through direct interaction with the world, particularly through our everyday visual, touch and kinesthetic experiences, we have practiced and refined these ideas for years.

"...The invariants of ecological physics are not the same as the invariants of physics" (Gibson, 1982, P. 217). Alternative conceptions can be viewed in the context of ecological physics. Gibson defined ecological physics as what there is in the environment to be directly perceived. An individual senses the environment and perceives *affordances*, those invariant properties of objects in the environment that afford opportunities for action by the individual. An individual's goal-directed exploratory actions drive selective perception, and attention and perception are honed and tuned through multiple interactions with environmental stimuli. In this way, learning often takes place directly through perceptual means, rather than through propositional reasoning.

People perceive what they know to look for; their schemata together with the information available in the environment drive perception (Neisser, 1976). Neisser's model of the perceptual cycle (Figure 1) holds that people anticipate and seek out information in accordance with anticipatory schemata or plans. When the looked-for information is found, it in turn modifies the schema. The modified schema in turn directs further exploration.

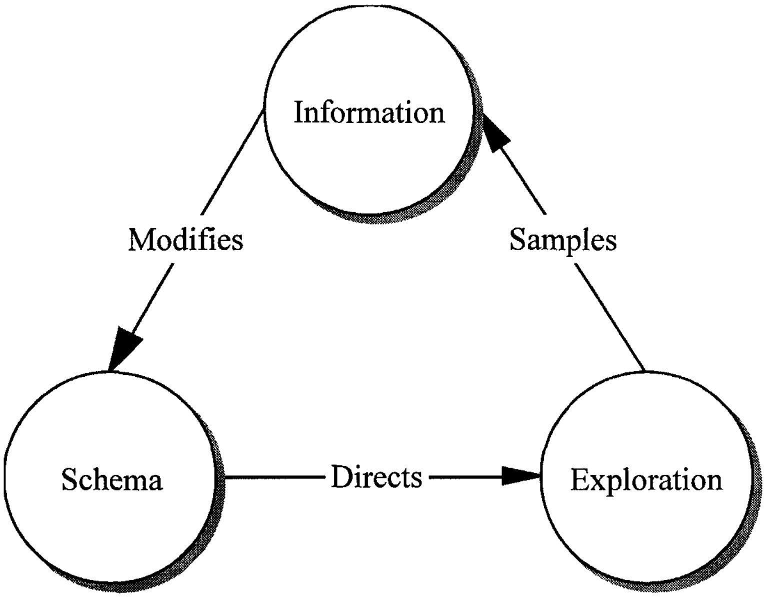


Figure 1. The Perceptual Cycle (after Neisser, 1976).

Learning to perceive specific affordances becomes automated through repeated interactions in similar situations; in other words, this automaticity is situated. It is unlikely that improving your tennis shots will improve your billiards shots. When an affordance disappears from awareness, it has become "transparent" due to the unification of *effectivity* (skill and ability) and affordance. The tennis racket disappears, becoming an extension of the player's arm and intention.

The propensity to predict plays a role in knowledge construction. For instance, people tend to recall information and facts based on their plausibility within a story context, whether or not they actually appear in the story (Anderson, 2000). The concept of plausible retrieval can also apply to predictions we make based on our understanding of the way the world operates, whether these understandings are scientific or not. Plausible retrieval plays a role in the sense that making predictions involves recognition of patterns based on prior experiences, and most of us have more real world experiences than experimental experiences or scientific knowledge of physics. For example, we know that moving objects will eventually come to rest because we have seen them do so time and time again. Learners cling to such commonsense beliefs because they are useful for making predictions. Howard Gardner has likened alternative conceptions in science to stereotypes in other fields (Viadero, 1999).

Palmer, (1999) found that learners sometimes reconcile seemingly contradictory conceptions by using an "if-then" reasoning strategy. Students can hold contradictory models that they use within different problem contexts. Because of this, they do not perceive them as inconsistent. They may have a formal model that they use for science class and a real world model that they use for everyday purposes. According to Landry and Forman (1999), children use analogy to explain a new event or phenomenon by comparing it with similar cases previously experienced.

Alternative conceptions can be difficult to dislodge if they continue to serve their explanatory function. Posner, Strike, Hewson, and Gertzog (1982) assert that dissatisfaction with a conception is a necessary impetus for conceptual change to occur. Making the learner aware of an anomalous situation that does not fit a currently held conception can serve to create cognitive conflict for this purpose. Additionally, a new conception must be deemed intelligible, plausible, and potentially fruitful before the learner will adopt it. However, Dekkers and Thijs (1998) reported greater success in helping students overcome alternative conceptions by building upon students' correct conceptions than they did with the cognitive conflict method.

Children's Conceptions of Force and Gravity

A number of researchers have investigated children's conceptions about force and gravity. Piaget, (1970) examined children's understandings of force and physical causality and found that children often equated force with being alive, being large, or having a useful purpose. Palmer (2001) interviewed 112 students in grades 6 and 10 to uncover their ideas about gravity and whether these ideas could be deemed scientifically acceptable. He found that 11% of sixth graders and 29% of tenth graders in the study held scientifically acceptable ideas; the rest held a mix of acceptable and alternative ideas. There was also a gender difference, with no sixth-grade girls and only one tenth-grade girl expressing scientifically consistent ideas about gravity.

The nature of children's misconceptions about gravity varies, and some of these misconceptions can persist into adulthood. In Palmer's study, some children expressed the belief that gravity is a force that acts only in the presence of air. Some believed that gravity only acts on a falling ball, not a ball traveling vertically upward. Some children found no relationship between weight and gravity; others thought that heavier objects fall faster (Palmer, 2001). This may have some basis in ecological physics; we can readily see that a less massive object like a sheet of paper falls more slowly than things like schoolbooks do. Other confusions may arise from differences between everyday language and scientific language. In one study, students were found not to differentiate between the use of the word 'force' to refer to physical forces and the metaphorical use of the word, as in 'my mom forced me to get up this morning' (Hart, 2002).

Promoting Conceptual Development through Media

Computer-based simulations can serve as virtual laboratories and provide learners with real-time feedback as they interact, modify variables, and repeat experiments that are sometimes difficult to perform under normal classroom conditions. Computer simulations can help learners visualize and comprehend difficult concepts. For these reasons, they can provide a powerful means for developing scientific conceptions.

Simulations provide a way of experiencing relationships among variables more directly than can be done simply reading about them in a textbook. Simulations can provide immediate feedback, linking cause and effect, action and perception of results. They can provide opportunities to more quickly developing a knowledge base through repeated experimentation. Since simulations typically require little set up time and variables can be modified quickly, more experiments can be run in a class period than could be accomplished with physical lab apparatus. And because effective simulations tend to focus on the essentials, the problem of too much information with resulting cognitive overload may be mitigated.

Many students find traditional lecture and textbook science education boring because it is too abstract and removed from direct action and perception. In their study, Hynd, McNish, Qian, Keith, and Lay (n.d.) found that students tended to avoid reading texts, were most likely to read the textbook right before a test, and were most likely to become disruptive during in-class reading assignments. Both students and teachers in the study were somewhat negative with regard to texts, and textbooks were not very effective in promoting conceptual change in concepts of motion. However, a benefit of both textbook and lecture notes is that they allow for reflection. User-controlled simulations afford the opportunity for reflection as well. The learner can stop, modify, and restart the simulation, actions that often are not possible in actual laboratory experiments.

Feedback informs us when we are performing adequately and helps us adjust our performance when necessary. Feedback is important for learning and it is also important to maintaining an optimal level of challenge (Csikszentmihalyi, 1990). Technology can provide this kind of immediate feedback that is conducive to maintaining flow and constructing knowledge. Neisser's (1976) model of the perceptual cycle (Figure 1) provides a useful model of learning through interaction with a simulation. A learner explores, perceives the result, modifies his or her schema, and then tries something else. Under some conditions, student understanding may regress after using a simulation. This may be due to a lack of understanding of the concept underlying the simulation, so that feedback is misinterpreted. Students sometimes misinterpret and make a connection to an instance that is not truly analogous (Monaghan & Clement, 1995).

This points to the need for guidance and structure. Computer-based simulations are not a panacea or a substitute for instruction. Gredler (1996) noted that a systematic strategy for conducting investigations is important for the effective use of simulation. Unstructured investigation using simulation is as ineffective as unstructured experimentation in a laboratory setting.

Simulation and Science Learning: Methods of Investigation

Interview is often used as a method of investigation to uncover the nature of students' understandings of science concepts. Piaget (1970) used interview methods to investigate young children's ideas about physical causality, including force. He had children of various ages define terms, explain causes of phenomena, and conduct simple experiments and explain the results. He used this as a means of describing the developmental changes that children undergo in their reasoning about the concepts in question.

Another approach to uncovering beliefs is to have subjects view diagrams or graphics that represent a situation, concept, or event and then have them respond to questions. McCloskey, Caramazza, and Green (1980) used this approach while having subjects predict the paths of balls that were about to emerge from various curvilinear tubes depicted in diagrams. Subjects responded by drawing a predicted path for each situation.

Palmer (2001) used simple diagrams to probe children's beliefs about gravity. The diagrams depicted various objects in various conditions, and children were prompted to circle the objects that gravity was acting upon. They were then interviewed about their responses to uncover their reasoning about gravity.

A benefit of interview is that one can ask follow up questions to clarify surprising or confusing responses, and delve more deeply into the subtleties and complexities of subjects' knowledge constructions. In a descriptive case study, Monaghan and Clement (1999) used interview methods to investigate the impact of a computer simulation on students' understanding of relative motion and whether they were able to use what they had learned from interaction with the simulation to create mental simulations. They used a think-aloud protocol with a predict-observe-explain format. That is, subjects predicted what they expected would happen in a particular scenario, articulating the reasoning processes used to reach that conclusion. They then watched the simulation run and responded to the results by explaining whether the results were as expected or not, and why. This approach is similar to the method that is being proposed for this study.

Imagery, Media and Modes of Perception

Sensory perception and feedback are invaluable tools for conducting inquiries, real or simulated. Visual-spatial thinking is essential for creativity and communication in the sciences, but tends to be neglected in science classrooms (Mathewson, 1999). Being largely visually based, multimedia simulations offer an opportunity to practice and build upon these skills. Indications are that at least some physics students make use of imagery while working through problems and making predictions and that students may use recall of simulated events to generate imagery. Students may also generate inaccurate imagery (Monaghan & Clement, 1999).

Both real time multimedia simulations and video offer the benefit of motion, which is difficult to ignore. It is likely that the learner will select and attend to something that is moving, especially if everything else is stationary. Beichner (1995) capitalized on this aspect of perception in the design of VideoGraph, a software program that links video of physical motion events with graphs of the motion in real time. Students who used VideoGraph had better scores on a standardized test of kinematics graph interpretation skills than students who were instructed by more traditional methods.

Different kinds of objects and media representations provide different benefits, constraints, and affordances. A video can be paused at a crucial point or played in slow motion to see a process in greater detail. Physical objects provide more of an opportunity to learn through manipulation and tactile sense than a multimedia simulation does, although virtual reality technologies such as haptic feedback are beginning to afford users some of these opportunities as well. Perhaps haptic feedback can be instrumental in helping learners to construct or reconstruct concepts by simulating direct sensory experiences that are difficult to experience in real life.

Haptic Interfaces: An Overview

Haptic interfaces are less commonplace than the primarily graphical interfaces that most personal computers employ today. High-end haptic interfaces are used for applications such as flight simulators, laparoscopic surgical simulators, manufacturing, and three-dimensional computer modeling. Inexpensive haptic input/output devices have been in the mainstream consumer market for several years, mostly to add to the feeling of presence or immersion while playing computer and video games. These devices take various forms such as joysticks, steering wheels, mice, and game controllers, and the haptic feedback they provide varies in quality and sophistication. Some of these devices merely vibrate or “rumble,” others simulate finer textures, and still others also provide force feedback.

Force feedback devices are powered by electric motors or other actuators that exert forces on the user. Tactile feedback devices usually employ pin arrays, vibrators, or rotating surfaces to simulate textures. Mice, joysticks and other kinds of haptic devices have varying sets of features that may make them more appropriate for one application than another. Force feedback devices can provide coarse feedback, fine feedback, or both. Coarse feedback refers to arm motion while fine feedback refers to finger motion. Coarse feedback systems without fine feedback, such as joysticks, will typically provide a handgrip that keeps the hand in a fixed position (Hasser & Massie, 1996).

Unlike tactile feedback devices, force feedback devices must be grounded. That is, the device is not entirely free moving, but is attached to some sort of base that gives the user something to push against with varying degrees of force. Inertial mice such as the iFeel™ by Logitech are free moving (not grounded), but there is nothing to push against to give a force feedback sensation, and so these mice can only provide tactile feedback.

Uses and Potential Benefits

Additional modes of sensory feedback can help to improve performance, particularly in situations where the primary mode (usually vision) is otherwise occupied (Norman, 1988). Hasser and Massie (1996) identified a number of benefits associated with haptic feedback. These included reduced training time, reduced task completion time, reduced dependence on vision for some tasks, reduced errors, and an increased sense of immersion in virtual environments.

A number of studies have supported the conclusion that haptic technology can improve performance by reducing task completion time and errors dramatically, sometimes by up to half (Burdea, 1996; Richard et al., 1996; Sallnäs, 2000). Haptic feedback can improve performance in tasks that require accurately locating (targeting) and clicking a button or other onscreen object. In non-haptic computer interfaces, visual (and sometimes auditory) feedback is used to confirm users' actions. Users are able to target their clicks more quickly and accurately with the addition of haptic feedback. Without it, subjects tend to click in the center of the target object. With haptic feedback, subjects tend to click as soon as the target is felt, and the target is felt as soon as the cursor is within its boundary (Burdea, 1996).

Educational Applications of Haptic Feedback

Various studies with visually impaired mathematics and physics students have shown that haptic technology may hold great potential for making computer- and Web-based instructional materials more accessible. Van Scoy, Kawai, Darrah, and Rash (2000) developed a haptic interface for teaching math to visually impaired students. Users may enter a function as a line command and the program will render the graphed line haptically, so the user can feel the graphed result.

Wies, Gardner, O'Modhrain, Hasser, and Bulatov (2000) developed a Web-based learning module with a haptic interface to help blind undergraduate and graduate physics students learn about electric fields. The experimental mode of the application allowed the students to test the electric charge on a sphere by feeling the force attract or repel their hand. The students could record the force data at a particular radius by clicking. In analysis mode, the student had the option of allowing the computer to take control of the mouse and trace the shape of a curve, taking the student's hand along with the mouse. Student feedback indicated that this would be a useful learning tool even for students with normal vision.

In studies (such as those described above) with visually impaired subjects, haptic feedback is compensating for a lack of visual feedback. From a theoretical perspective, it is not clear whether and under what conditions haptic feedback may interfere with visual feedback. According to dual coding theory (Paivio, 1986), people process stimuli through two channels, verbal and non-verbal. The verbal channel includes symbolic systems like written words (visual system), spoken words (auditory system), and handwriting (haptic system). The nonverbal channel includes visual objects, environmental sounds, the feel of objects, taste memories, and olfactory memories. If a simulation presents a visual object moving on screen together with the feel of the object moving, will the two sensations utilizing the nonverbal channel create cognitive overload? Or, since the two sensations are coming through two sensory modes, may the effects be complementary?

Oakley, McGee, Brewster, and Gray (2000) studied the effectiveness of force feedback within a graphical windowing system as a means of relieving visual overload that computer users may experience with desktop clutter and multiple open application windows. Unlike most previous studies, their preliminary results showed that the test subjects did not complete their tasks more quickly. However, they did make significantly fewer errors and also reported the perception of a decreased workload. This raises the possibility that haptic feedback may help to reduce cognitive overload.

Mayer (2001) found that related visual and verbal information that was linked temporally was more effective (as measured by greater learning and transfer) than when the information was displayed separately. Mayer named this the "temporal contiguity principle." If, as in the case of the simulation to be used in this study, related visual and haptic information is synchronized, it seems likely that this would also prove more effective than presenting the two modes of information separately.

It is also likely that some content lends itself more readily to haptic treatment. Like the application of haptic feedback to surgical simulators, its application to simulations of physical forces for educational purposes directly relate to the content. In the first case, though, the goal is for the learner to acquire a procedural skill that has a critical haptic basis. In the second case, haptic feedback is being used to support the development of conceptual understanding. Teaching about physical forces like gravity, friction, elasticity, and inertia would seem to be a natural application of haptic technology. The force sensations themselves are, in essence, the content. Reiner (1999) studied the application of embodied knowledge to teach physics to learners who had a minimal physics background. Subjects in Reiner's study used a haptic trackball to sense fields of forces that were invisible (not represented visually on the computer screen). The subjects then drew diagrams depicting what they felt. The subject's diagrams were remarkably similar and accurate when compared with those that would result from complex physics calculations. The students invented a symbol and concept comparable to vector lines to describe their haptic experience.

A potentially powerful application of haptics may be to help students overcome alternative conceptions, such as the notion that constant force results in constant motion rather than acceleration. A computer simulation with haptic feedback can, for example, simulate a frictionless environment that does not exist in everyday life by providing a basic sensory experience to help counteract the ingrained concept.

In summary, computer simulations with visual and haptic feedback may offer features and benefits that can make them effective tools for helping students to construct more powerful understandings of conceptual physics. They can allow more opportunities for practice and trying out ideas; make concepts more "real" (concrete); support a more meaningful experience, with learner action tightly coupled to the perception of results (immediate feedback); and provide a multi-sensory experience.

Due to these qualities, computer simulations offer potential to help learners acquire scientific conceptions, provided they are used with a sound pedagogy. Simulations can provide a safe, non-threatening environment in which to experiment, receive feedback, pause to reflect, quickly play with ideas, modify variables, and perceive results.

Learning Styles and Modal Preferences

One definition of learning styles is "the preferences, tendencies, and strategies that individuals exhibit while learning" (Thomson, 1997, page 1). Although there has been interest in individual learning styles since the early Greeks (Lemire, 1998), in recent decades there has been increased attention paid to meeting the needs of individual learners with varying styles or modes of learning. One has only to type "learning styles" into a Web search engine to be met with an enormous number of sites devoted to this topic. Many of these are targeted at college students, adult learners, or the parents of younger learners. Often these sites provide self-assessments and tips or strategies for more effective learning.

The umbrella of learning styles covers a plethora of concepts. These include aspects of personality, cognitive styles, and environmental preferences. One widely used model known as the Dunn Model (or Dunn and Dunn Model) is also one of the most comprehensive. It includes 21 elements grouped within five categories (environmental, emotional, sociological, physical, and psychological) that are said to influence learning. Other models focus on a narrower aspect of learning preferences such as information processing style or Jungian personality type.

One aspect of a learning experience or environment is the sensory mode or modes (visual, auditory, haptic, or multi-modal) in which information is provided and/or learning takes place. Best practices dictate that a classroom should offer learning opportunities in a variety of modes to meet the needs of most learners. For example, lecture or discussion may be more effective for those with an auditory preference, while reading or viewing graphics may benefit those with a visual preference, and hands-on work may tend to benefit those with a haptic style. Perhaps a simulation such as the one to be used in this study that provides both visual and haptic feedback will be more effective with haptic learners than a simulation that provides only visual feedback. Conversely, it is possible that the added stimulation of force feedback could detract from learning for those with a predominantly visual preference.

There has been criticism that the term “learning styles” is too broad or generic to be of use. Lemire (1996) states, “learning style or modality should be confined to the model which allows for visual, auditory and haptic preferences” (P. 47). Yet even within modal preference models, terms are not so clear-cut. Some assessment instruments separate the haptic dimension into tactile and kinesthetic; still others subdivide visual into visual-nonverbal and visual-verbal (i.e., reading written text).

As previously noted, there are numerous instruments for assessing learning styles. Many are free, informal self-assessments; others are available for a fee from various publishers or coaching centers. Learning style instruments have been criticized for the lack of a research basis and weakness in (or nonexistence of) reliability and validity data. For example, Deaton (1992) criticized the Learning Channel Preference Checklist (LCPC) for lacking in so many areas (e.g., lack of research basis, no evidence of the psychometric properties of the scores) as to prevent consideration of its use. In discussing the well-known and widely-used Learning Style Inventory (LSI) which is based on the Dunn Model, Hughes (1992) states, "Research and test development in the field of individual learning styles has been plagued by poor attention to issues of construct validity and theoretical development" and further that the instrument "exemplifies all of the problems characteristic of instruments designed to measure learning styles" (p. 460). In a later review of the LSI, Knapp (1998) noted that the earlier harsh criticism seemed to have had a dampening effect on the use of the instrument for research in the intervening years.

Yet the instrument remains popular, and the Dunn Model is still being recommended to teachers as having applicability to the classroom, including the math and science classroom (Thomson & Mascazine, 2003). Lemire (1996) cautions against discarding the idea of learning styles completely, noting that there is evidence for congruence in subjects' scores across various learning style instruments with inter-assessment score agreement of 75% in one study, though he agrees that work needs to be done in the areas of instrument validity and reliability.

There is evidence that learning styles are developmental (e.g., Lemire, 1996), and that even in adults they are not fixed. In a large survey study of learning style preferences among English language learners in U.S. colleges, Reid (1987) noted that respondents varied widely in their preferences depending on their cultural background and their length of time in the U.S. The longer subjects remained in this country, the more their preference profiles resembled those of native English speakers.

Force Feedback as an Aid to Concept Development

This chapter has discussed literature that describes the importance of touch to cognition and concept development, particularly in our interactions with the physical world. Studies about the acquisition of science knowledge were discussed; numerous studies have shown that alternative ideas about science can and do interfere with the development of academic science concepts. The concept of gravity has been shown to be difficult for learners to comprehend adequately. In several studies, simulation has been shown to be an effective tool for developing a more accurate understanding of science concepts. One effective method is to have learners predict what will happen before the simulation is run and then explain the results, whether the prediction was right or wrong. Interviewing students about their reasoning can uncover some of the more subtle conceptual relationships that may not be apparent initially.

Several studies have shown potential for force feedback as an aid to learning. Several of these employed haptic feedback as a means of creating an accessible interface for learners with visual impairment. But the most intriguing studies for the purposes of this study were those that examined applications of force feedback to aspects of physical science that could not be easily, or perhaps as effectively, conveyed by other means. These studies are few, and they were conducted with young adults as subjects. The goal of this study was to examine the effect of force feedback on conceptual development with younger subjects, namely fifth grade students.

Chapter 3: Method

Introduction

This research project was designed as a case study that employed both qualitative and quantitative methods. It was exploratory in nature, and was designed to investigate what, if any, effect force feedback had on children's conceptions of mass, gravity, force and motion.

A case study approach is appropriate for examining the thoughts of fewer students in greater depth rather than more students in a cursory manner. Experimental and quasi-experimental studies tend to focus on the outcome of instruction rather than the process of learning, the study of which lends itself to a more naturalistic approach. Case study research can uncover potentially useful ideas and hypotheses for further investigation (Monaghan & Clement, 1999). Case study research takes place within a bounded system (Creswell, 1998). The bounded system for this study is a single case, consisting of the students who participate in guided inquiry with the paddleball simulation. The system for this study was bounded by time (fall 2003; approximately 60 minutes instruction and interaction with each participant), place (three elementary schools in the greater San Diego area) and scope (34 subjects' interactions with a technology tool and their cognitive and affective responses to the experience).

The researcher anticipated that students' understandings of the target concepts might be affected by the addition of force feedback, especially in those instances where the concepts in question were more obvious when sensed haptically (e.g., changes in weight). Regarding concepts that do not have such a strong haptic component, it was anticipated that there would be little or no difference in the two groups, or that haptic feedback would interfere with learning.

Figure 2 provides an overview of the main and subordinate research questions, and a summary of how these questions were investigated.

<table>
<tr><td colspan="2">Question. Does working with the simulation affect students' conceptions of gravity, mass, force, and/or motion?</td></tr>
<tr><td>Data Used</td><td>Method of Analysis</td></tr>
<tr><td>Pretest/survey
Guided inquiry worksheet
Observation notes
Interview notes and recordings
Posttest</td><td>• Classified and coded pretest responses based on their content using constant comparison.
• Classified and coded interview data based on content using constant comparison.
• Compared pretest with interview data to determine whether there was a shift in students' understandings of basic concepts.
• Compared interview responses to posttest responses to check for consistencies and inconsistencies in understanding.
• Analyzed content of students' rules, predictions, and posttest choices qualitatively to look for themes and relationships. Described the nature of conceptual shifts.</td></tr>
<tr><td colspan="2">Question. Does force feedback affect students' conceptions of gravity, mass, force, and/or motion?</td></tr>
<tr><td>Data Used</td><td>Method of Analysis</td></tr>
<tr><td>Pretest/survey
Guided inquiry worksheet
Observation notes
Interview notes and recordings
Posttest</td><td>• Compared students' comments, rules, predictions, and posttest scores to determine whether there is a difference between treatment and control groups in their understanding of these concepts. Analyzed content of responses qualitatively and describe the nature of any conceptual shifts.
• Used chi-square analysis (cross-tabs) and independent t-tests to determine whether any difference between treatment and control group scores is significant.</td></tr>
<tr><td colspan="2">Question. Does the effectiveness of force feedback vary depending on the subject's modal learning preference, gender, or prior knowledge or experience?</td></tr>
<tr><td>Data Used</td><td>Method of Analysis</td></tr>
<tr><td>LCPC scores
Demographic data
Pretest survey
Scores on rules, predictions, and posttest data</td><td>• Used independent t-tests to determine whether subjects' rules, predictions, and posttest responses vary by modal learning preference, gender, or prior knowledge or experience.</td></tr>
<tr><td colspan="2">Question. Does the subject's satisfaction with the treatment vary depending on the subject's modal learning preference, gender, treatment, or prior knowledge or experience?</td></tr>
<tr><td>Data Used</td><td>Method of Analysis</td></tr>
<tr><td>LCPC scores
Demographic data
Pretest survey
Interview responses
Posttest responses</td><td>• Used independent t-tests to determine whether the subjects' responses to satisfaction with the treatment vary by modal learning preference, gender, treatment, or prior knowledge or experience.</td></tr>
</table>

Figure 2. Summary of research questions and methods.

Overview of the Methods

Within each of the three test sites, subjects were purposively selected and assigned to one of two groups based on their gender and modal learning preference as determined by the Learning Style Preference Checklist (LCPC) instrument. The aim was to have equal numbers of students in each group with regard to gender and modal preference. Having approximately equal gender groups was deemed important because of the preponderance of data showing that gender differences develop and widen between grades 4 and 8. An effort was made to distribute the various modal learning preferences equally between the groups, though the vast majority of students had a visual preference, and only one had a haptic preference. The experimental group (FF group) interacted with the simulation with both visual and force feedback; the control group (No FF group) used the simulation with visual feedback only. Demographic data and survey data regarding students' prior experiences with force feedback, video games, and content knowledge were gathered.

The primary data collection effort focused on observations, student-recorded data collection worksheets, and interviews. Subjects first interacted with the simulation using a guided inquiry approach. They were given a sheet with step-by-step directions for interacting with the simulation and a data collection worksheet on which to record their observations. During the experimentation, students were free to ask questions, and the researcher asked questions to elucidate students' reasoning with regard to the experiments. After completing the series of four experiments and recording the results, subjects were asked to develop rules that described concepts related to the experiments. Subsequent to this practice session, subjects were asked interview questions regarding basic concepts. Following this, subjects were asked to predict what would happen under various simulation conditions. They were then asked to carry out the experiment, and observe and explain the results.

The interview followed a semi-structured format. All subjects were asked the questions contained within an interview protocol. However, depending on their responses, some were questioned in more detail to further clarify the nature and shape of their thoughts about the concepts in question. If in the course of answering one question the subject answered another, their response was restated and they were prompted to confirm and further explain or add more detail if they wished.

The entire session was audio recorded; this included the experimentation, rule generalization, and interview portions. Subjects were encouraged to "think-aloud" and explain their written responses as they worked through the experiments. Transcripts of the recordings were coded and analyzed for the purpose of understanding the nature of the subjects' conceptions about gravity, mass, force, and motion within the context of the simulation.

After the experimentation and interview, subjects completed a multiple-choice, multiple-answer content assessment. This posttest assessment was scored and compared with the results from the pretest and interview data to determine the extent of the subjects' consistency of thought with regard to the concepts in question.

Mixed methods were used to analyze the various data as detailed in Figure 2.

Design of the Study

The major steps of the study are given in Figure 3. The steps are generally listed in chronological order, although some tasks ran concurrently.

- Located and/or developed instruments (Summer 2003)
- Located school sites (August-September 2003)
- Piloted instruments/data collection and revised
- Scheduled data collection
- Secured permission from parents, students
- Assessed modal learning preferences
- Collected demographic data, pretest and prior experience survey data
- Assigned subjects to one of two groups (per school): visual & force feedback (experimental) or visual only (control) based on gender and modal preference
- Had students conduct experiments with the simulation (with guidance sheets, audio-recorded)
- Interviewed students (audio recorded); had students explain the results of their work, define concepts, make predictions, observe and explain results
- Administered posttest
- Scored posttest
- Transcribed audio recorded data (transcribing service)
- Coded transcript data using constant comparison method
- Analyzed data, looking for patterns by treatment, modal learning preference, demographic, prior knowledge, conceptual consistency
- Reported results

Figure 3. Steps in the study.

Software and Instruments

The paddleball simulation "FEELitPaddle.exe" was created by Immersion Corporation and supplied as a demonstration program with the Logitech® WingMan® Force Feedback Mouse (WFFM). The simulation interface consists of two interactive windows. The main window contains the paddle, which the user can control and manipulate with the WFFM, and the ball, which the user can manipulate indirectly by striking it with the paddle. The smaller window contains four variable parameter controls. These four variables are mass (of the ball), gravity (toward the bottom of the window), stiffness (of the paddle), and damping (creates the sensation of playing while immersed in water or a more viscous substance). For the purposes of this study, mass and gravity were manipulated. The slider controls range on a scale of 5 to 100, signifying the strength of the programmed haptic effect, so that 5 represents a minimal, barely noticeable effect and 100 represents a very strong effect. For conceptual purposes only, a setting of 5 for gravity might represent the gravitational pull of the Moon and a setting of 100 might represent the gravitational pull of Jupiter. For mass, 5 might represent a ping-pong ball and 100 might represent a lead ball.

Only one window can be active at a time, so the variable parameters cannot be changed while the subject is interacting with the paddle; the activity must be stopped and then resumed with the new settings in effect. A screen diagram of the software and control panel can be seen in Appendix A. The software control panel was used to control mass and gravity settings. A photograph of the mouse that was used in the study is included in Appendix A.

Learning Channel Preference Checklist-Revised (LCPC)

A number of instruments have been developed that purport to assess a learner's preferred mode of instruction (e.g., visual, haptic, or auditory), sometimes in addition to other learning style preference factors like time of day, temperature, and so on. Some of these are self-assessments, originally developed for use by college students; others are observation checklists for teachers to use to assess younger students.

The LCPC has been widely used to assess modal preferences of learners of various ages. The ability to reflect with regard to one's own learning is developmental, and usually is not sufficiently developed enough before about age eleven for students to self-assess their optimal learning mode according to the author of the LCPC, Dr. Lynn O'Brien (personal communication, April 14, 2003). According to O'Brien, the original LCPC development began in 1979 for use by college students with learning disabilities. Over the years, it has been tested and modified for use by other populations such as language learners (e.g., Kroonenberg, 1995). The *Eleventh Mental Measurements Yearbook* identifies it for use with grades 5 to adult; the author recommends it for ages 11 to adult. A study of the LCPC with 6,000 students in grades 5-12 in the United States, Hong Kong, and Japan found no statistically significant differences in modal preferences based on age, gender, culture or ethnicity, but did find a preference for haptic learning in all groups (O'Brien, 1991). In another study with language students at an international school in Hong Kong, a slight visual preference was shown. Again, there was no significant difference with regard to age, gender, or ethnicity. In many cases, students were fairly balanced among the three modalities, and some students indicated a preference of two modalities (Kroonenberg, 1995). This contrasts with another study, which showed that students' learning style preferences shifted as they aged, with children being more equally divided among the modal preferences. Adults strongly preferred visual, followed by haptic and then auditory (Lemire, 1996). Kroonenberg's study also contrasts with a study by Reid (1987), which showed marked differences among English language learners from different cultures with regard to their modal preferences.

The reliability of the LCPC, calculated with Cronbach's alpha (for consistency) corrected by Spearman-Brown Prophecy Formula is .98. Individual scale reliabilities are visual: .62, auditory: .62, and haptic: .69.

Face validity. The LCPC has been used by thousands of students over the past two decades, including more than 200,000 students over the past three years at Sylvan Learning Systems.

Predictive validity. According to Oxford, "In terms of validity, the LCPC was helpful in predicting language achievement in a Japanese satellite program." (letter from Rebecca L. Oxford to Lynn O'Brien, dated December 23, 1992).

Examples of items included in the LCPC include:

I need to discuss things to understand them.

I take lots of notes on what I read and hear.

It's easier for me to get work done in a quiet place.

I am able to visualize pictures in my head.

I take notes, but I never go back and read them.

Other Instruments

The following instruments have been developed by the researcher with input from a content specialist and several colleagues, parents, and test subjects. They were pilot tested and revised several times during the months of June-August 2003. Some of the language was simplified or reworded, the worksheet was reorganized into table format for easier comparison of data, and the number of experiments was reduced to four both to shorten the treatment and to present only the most extreme conditions of the variables in the experiments.

Pretest and survey. A brief self-report questionnaire was created to assess subjects' level of prior knowledge of major concepts (i.e., gravity, mass, force) and prior experience with games and force feedback technology. The word "occasionally" was too difficult for many students and was replaced with "once in a while" as suggested by one subject. The instrument is included in Appendix B.

Directions Sheet. This instruction sheet presents a screen shot of the simulation with brief instructions and guidelines on how to interact with the software. See Appendix B.

Guided Inquiry Worksheet. This printed worksheet guided subjects through experimentation with the simulation and provided a framework to record and compare their observations. The subjects completed four experiments: low mass/low gravity, high mass/low gravity, high mass/high gravity, and low mass/high gravity. A few questions that asked subjects to make rules about the behavior of the simulation followed the experiments. The researcher was present to observe and to clarify steps and answer procedural questions, but subjects were asked to record their own data. The completed worksheet was discussed with the subject during the subsequent interview.

The worksheet was modified several times to be as self-explanatory and standalone as possible, but during the pilot the majority of the students required some degree of modeling and support during the experiments. This was the case during the study as well. Students were encouraged, though not pressured, to "think aloud" during interaction with the simulation. This happened spontaneously with one of the subjects in the pilot, and her running commentary provided a vivid view into the developing process of her ideas about the concepts. Participants were questioned about their results as they worked through the experiments.

The follow-up questions were reworded to ask that the respondents 'make a rule' about a behavior of the simulation; previous wording asked them to 'look for patterns' in the data which tended to cause them to look for sequential patterns rather than overall patterns. One thought was that the word 'pattern' was causing them to think back to previous math class experiences and the admonition to "find the next number in the pattern." Even with rewording, however, most students needed support to work through the questions. This instrument is included in Appendix B.

Interview Protocol. As described previously, the format of the interview was semi-structured. The interview protocol lists the questions that all participants were asked. These included a review of their work with the simulation and having them provide definitions for key terms. Depending on their responses, unscripted follow-up questions were asked to elucidate their responses or elicit more information.

Students were prompted to predict what would happen under specific changes in the simulation conditions. The students were also asked to elaborate on their thought processes. The students then performed the experiment under the conditions described, and explained whether their predictions were correct or not, and why.

Finally, students were asked to reflect on their learning and their satisfaction with the experience. The interview protocol is included in Appendix B.

Posttest and satisfaction survey. The content assessment consists of six items with multiple-choice/multiple answer format. That is, there may be more than one correct answer, and the subject may choose as many answers as he or she feels appropriate. This instrument also includes three point Likert-scaled items designed to rate user satisfaction with the experience of using the simulation.

One finding from the pilot of the instruments was that the word "speed" could be interpreted in different ways. It was initially intended that speed refer to the general impression in comparing low and high gravity situations. Many of the pilot subjects were more discerning than this, noting that the ball moved more quickly at first, and then more slowly the more times it bounced. Others also appeared to notice that the ball moved quickly when it was struck with more force (since it had more time to accelerate), and that it also bounced more times.

Mostly during the interview and especially during the posttest, it became apparent that several subjects linked changes in mass to changes in speed. In referring to a high mass/low gravity run of the simulation, one subject stated that the ball did not feel heavy when it was just sitting there, but it felt heavy when she tried to move it. This was a good description of inertia, and the only clear reference to the concept during the pilot. It caused the consideration of whether subjects may have been equating increased effort required to get the more massive ball moving with the concept of speed. For this reason, the posttest items were reworded to refer to speed while falling. Since there were no items that dealt directly with inertia, one answer choice was changed to "the ball becomes harder to move" in response to a question about an increase in mass.

Sample and Population

Thirty-four fifth grade students from three elementary schools in San Diego County, California participated in the study. The three school sites varied in many respects, summary data regarding economic status and computer resources are shown in Table 1.

Table 1

School Data for 2002-2003

School	Free and reduced price meals	Number of Computers	No. of Students per Computer	No. of Classrooms with Internet
School 1	158 (35.5%)	25	17.8	21
School 2	15 (2.7%)	71	7.9	29
School 3	546 (88.8%)	59	10.4	31

Fifth grade students were chosen for several reasons. By fifth grade, most students are mature enough to reason and give thoughtful responses to written and verbal questions. They are still in elementary school and preadolescent, and so are not subject to some of the developmental and social factors that may affect receptivity to the treatment. Fifth grade is at the beginning of the grade cluster 5-8 when girls' performance in science began to decline in relation to boys' (Mullis, Martin, Fierros, Goldberg, & Stemler, 2000), and it was anticipated that most fifth graders have not studied the content in great detail. Since many fifth graders are in a single classroom all day rather than a different classroom each class period, and since the simulation practice and interview was expected to take roughly one hour per student, a single classroom environment was anticipated be the least disruptive and most expedient environment for data collection. Subjects were required to be relatively proficient in English, because this study relied heavily on interview data. During the pilot study it was determined that subjects needed to be able to articulate the subtlety of their thoughts and conceptions with a degree of precision. The sample was selected purposively according to the following criteria.

Group assignment was done on a per site basis. The experimental and control groups were to be of equal size. Genders were to be approximately equally represented, and genders were to be approximately equally represented per group. A total of 16 girls and 18 boys participated in the study, with 8 girls and 9 boys per group. Modal learning preferences were to be approximately equally represented in each group, although due to the other constraints this was not always possible. The modal learning preferences for each group are shown in Table 2.

Table 2

Modal Learning Preferences by Group

	Modal learning preference						Total
	Visual	Vis./Aud.	Vis./Aud./Hap.	Auditory	Haptic	Hap./Vis.	
FF	11	1	1	2	1	1	17
No FF	10	4		3			17
Total	21	5	1	5	1	1	34

The first subject of each gender and learning style at each test site was assigned to the experimental group. After that, the assignments alternated. The determination of who was the "first subject" varied from site to site. In the case of the first site, parental consent forms trickled in, so assignment was done on a first-come, first-served basis. In the case of the second school, the science teacher had created a master schedule with student assignments, and this determined the order. In the case of the third site, order was determined by the order that surveys were returned, so as not to reward the misbehavior of a couple of students who had completed their surveys late because they were off-task.

Data Collection

Overview

Parental and subject forms were collected from all participants before any data were collected. Observation field notes by the researcher supplemented the guided inquiry worksheets and audio recording of the session. The researcher took notes during the interview, and each student completed a posttest.

The LCPC was administered to 34 study subjects. Participants were purposively assigned to one of two groups on the basis of modal preference and gender. Demographic data and experience survey data was collected from the study participants.

Subjects participated individually during the treatment and interview. The researcher read through the directions with the participants and answered any questions regarding the procedure. The participants had the printed directions available to refer to during the simulation practice, though in practice this was rarely used. Participants were given a few minutes for free exploration of the simulation prior to the guided inquiry portion. A worksheet of printed questions and instructions (the guided inquiry worksheet) was used to guide the student through the process, together with prompting from the researcher. The participants provided written observation notes on this worksheet for each of the simulation experiments, and these were analyzed for content.

After the guided inquiry period, participants were interviewed, following the interview protocol. They were asked to provide definitions of key terms. They were asked to predict what would occur under certain conditions of the simulation. They were then asked to run the simulation under those conditions and to observe and interpret the results. The experimentation and interviews were audio recorded. Once they had completed the interview portion, each student concluded their participation with a written posttest and satisfaction survey.

Description of the Data Collection Process

Data were collected from mid-October through the first week in December, 2003. The scheduling of the data collection varied depending on the school. School 1 data collection took place on Tuesday and Wednesday afternoons, during the time that students would normally be studying either science or social studies. Data collection at School 2 took place on Monday, Thursday, and Friday afternoons, during science instruction time. Data collection at School 3 took place anytime after math instruction, which was scheduled during first period. Interruptions to the data collection schedule included fire drills, special assemblies, student absences, safety duty, parent-teacher conferences, holidays, and school closings due to wildfires.

Most students completed the subject consent forms, pretest and LCPC survey in groups; a few did so individually. Following this, students were pulled individually from class to complete their participation. The individual work took place in settings that varied but were adequate, providing enough space and quiet for recording purposes. In School 1, the only space available was the former computer lab, which had been re-purposed as a crowded storage room. A small table and two chairs were found among the clutter, and this was sufficient for the needs of the study. The room was usually quiet; teachers and other staff entered occasionally, but they made an effort to keep their voices low.

The science teacher at School 2 had reserved the literacy room for the duration of the data collection. This was a small room with two tables and lined with bookshelves filled with literacy materials. Occasionally teachers entered to browse the shelves, but they were quiet. The only disadvantage of this space was that the speech therapist occupied the adjacent office, so that small groups of young children would occasionally burst into song or recite loudly. The digital voice recorder was able to adequately minimize the effect of this background noise in dictation mode.

Space was limited and on a first come, first served basis at School 3. On most days the new computer lab was available. This was a large, quiet space adjacent to the library. Installation of the network and hardware was in progress, so the room was not yet available for use by students and teachers. On the one day that technicians were working in the lab, the after school program room adjacent to the cafeteria was available. This was less desirable because of the cafeteria noise, but it sufficed. On this same day, the electrical power was disrupted for about an hour, precluding the use of force feedback during that time. In all cases, the individual testing area was removed from the classroom.

This provided an opportunity for small talk about favorite school subjects and the like, as well as a quick refresher of what the child would be doing in the next hour.

The individual participation followed a similar format, as illustrated in Figure 4.

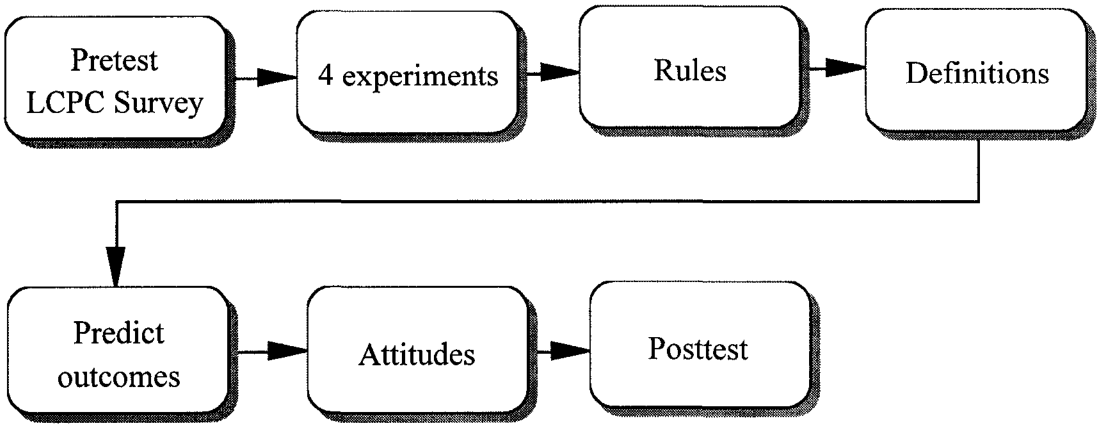


Figure 4. Flowchart of participant activities.

Each participant took a few minutes to become familiarized with the equipment and software. The participants reviewed the experiment worksheet as it was explained to them. They were encouraged to ask as many questions as they liked. They were also encouraged to think aloud as much as possible, because the session was being recorded to help the researcher understand how or whether the experiments were helping them learn. They were also told that they would be asked questions about their work as they progressed through the experiments.

Many participants were willing to talk freely; a few were more reticent initially and then began to talk more freely as they forgot that they were being recorded. One student whispered at first, asking whether he should state his comment aloud for the record. Another student was very quiet and hesitant to take any action on her own throughout most of the session. On each experiment, she kept bouncing the ball until she was told that she could move on to the next step whenever she was ready.

For each experiment, participants were presented with following questions:

Speed of ball?

How hard did you hit the ball?

Describe what you see and feel when the ball hits the paddle.

Number of bounces? (hit ball to top of screen)

For experiments 2 through 4, participants also were asked what had changed from the last experiment. The first experiment usually took much longer than the remaining three because the participants were learning the process. Spontaneously or with prompting, participants described factors such as the apparent speed and motion of the ball. When they came to the question about the number of times the ball bounced, the researcher modeled how this should be done, explaining that it was important to keep the method of bouncing as consistent as possible across the four experiments so that they could compare their data. Many participants repeated this part of the experiment to see whether the number of bounces remained consistent across multiple trials.

As participants continued on to subsequent experiments, they were asked what had changed from the previous experiment. After completing the four experiments, they were asked to generalize three rules, one about the number of bounces, one about the speed, and a third about something else that they had noticed. This was too difficult for the majority of students to do on their own; most required guidance to complete the process. They were prompted to review the data that they had collected, to look at the changing mass and gravity settings, and to think about and explain how the changing data were related to the changing variables.

Following this, students were told that they could take a break from writing and answer some additional questions verbally. These questions can be seen in the Interview Protocol, included in Appendix B. They were asked to define mass, gravity, and weight. Their responses often reflected the state of their prior knowledge as well as their experiences with the software. They were then asked how they could make the ball as heavy as possible.

Next, the participants were prompted to set up two experiments, try them out, and then predict what would happen if a variable were changed. They then changed the variable and discussed whether or not the results were what they had predicted. Following this, they were asked attitudinal questions about the experience. Finally, they completed the brief posttest and returned to class. The length of time for this entire process averaged about an hour for most students. A few students finished in fewer than 45 minutes, and one student took over 1.5 hours because he wrote very slowly and carefully, erasing and rewriting until he was satisfied with the quality of his penmanship.

Treatment of the Data

After recording each session, the digital audio files were uploaded to a transcription service. The transcripts were returned, usually several days later as email attachments. These were reviewed against the original audio files and corrections were made as necessary. These files were saved as plain text documents and imported into QSR's N6 qualitative analysis software for coding and analysis.

Transcripts were first coded by section or activity, then by content. Codes were developed from the data using the constant comparison method. The researcher assumed primary responsibility for the development of the codes, although the research assistant also developed codes later in the process. The researcher coded all transcripts for sections, as well as 26 transcripts for content. The research assistant coded the 8 remaining transcripts for content. The researcher reviewed these and adjusted the codes.

As codes were developed, similar codes were combined if they seemed redundant. Often similar codes were kept separate if the participant arrived at response by a different path, or if the response showed a deeper understanding than could be indicated by an existing code. For example, if a participant noticed that the ball was "heavy," that was determined to be fundamentally different from a dawning realization that increased mass makes the ball heavier, and so these were coded separately. Comments also were coded separately depending on their focus, so that "mass makes the ball heavier" was kept separate from “weight = mass,” since in one case the focus was on the effects of mass and on the other the focus was on defining weight. The codes were often combined later by using search tools. For example, all codes that talked about mass and weight could be examined together. As data were combined and analyzed by searches, some codes were combined with similar codes. The codes are listed in Appendix C, together with the number of documents that coded to them.

The pretest and posttest quantitative and demographic data were entered and analyzed in SPSS. An alpha level of .1 was used because of the exploratory nature of the study. These data were also imported into N6 so that qualitative responses could be compared with demographic data and posttest responses. Figure 2 outlines the research questions together with the methods of data analysis that were used to address them.

Chapter 4: Results

The purpose of this study was to investigate the effects of working with a computer simulation on student reasoning about mass, gravity and related concepts, and whether the addition of force feedback made a difference in student reasoning. This chapter begins with a summary of the study. It then reports findings for each of the research questions. The main questions focus on the development of students' conceptions of gravity, mass, force, and motion, and so each of these concepts are examined in turn. The roles played by prior knowledge, force feedback, gender, and game play are considered, and themes that emerged from the interview data regarding student reasoning are discussed.

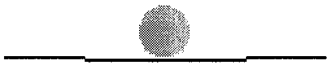
Summary of the Study

The students' participation followed a set procedure. First, they completed a pretest and learning style survey. Following that, they worked individually as they conducted a series of four experiments while completing guided inquiry worksheets. Next, they answered interview questions and made predictions about the outcomes of two experiments. Finally, they completed a posttest and attitude survey.

The simulation software used in the study was designed to simulate force feedback sensations under varying conditions of mass and gravity. This force feedback can be turned on and off. Figure 5 describes features of each of the experiments that participants were likely to notice. It also shows the appearance of the simulation under the varying mass and gravity conditions for each of the experiments. The line represents the paddle and the shaded circle represents the ball at their resting positions. The effects of the mass and gravity settings can be seen by the position and appearance of these elements. From the evidence provided by the changing positions and behavior of the software elements, participants drew conclusions about the effects of mass and gravity.

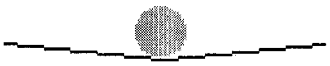
Experiment 1: mass 5, gravity 5

- Ball is light
- Small force required to make the ball go a great distance
- Takes a long time to return, can be over a minute if the ball was struck with strong force
- Paddle almost straight at rest
- Paddle does not give when ball strikes
- Bounces few times
- Moves downward at a relatively slow rate of acceleration



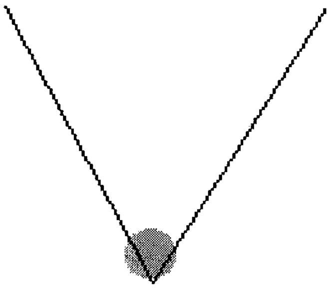
Experiment 2: mass 100, gravity 5

- Ball is heavier than Experiment 1
- More force required to push ball upward a similar distance as Experiment 1
- “Hesitation” or resistance to being pushed (inertia)
- Inertial force of ball pushes downward on the paddle causing elastic force of the paddle to shoot the ball upward
- Paddle bends into a “V” when ball strikes
- Ball bounces many times compared with other experiments
- Moves downward at a relatively low rate of acceleration



Experiment 1: mass 100, gravity 100

- Ball is very heavy
- Great force is required to hit the ball
- Ball does not go very far (impossible to apply enough force to make it go far)
- Ball returns almost immediately
- Paddle bends into a “V” when the ball is at rest
- Paddle extremely saggy when ball strikes
- Ball bounces fewer times than experiment 2
- Ball moves downward at a great rate of acceleration



Experiment 1: mass 5, gravity 100

- Ball not very heavy
- Significant force required to hit the ball any distance
- Ball does not go very far (impossible to apply enough force to make it go far)
- Ball returns almost immediately
- Paddle bends little at rest
- Paddle does not give when ball strikes (like ping-pong)
- Fewest bounces
- Ball moves downward at a great rate of acceleration

Figure 5. Key features of experiments and resting positions of the ball and paddle.

Participants

Participants were drawn from three schools, located in San Diego County, California, that elected to participate in the study. As discussed in Chapter 3, the three school sites varied widely in many respects, including socio-economic status, percentage of English learners, and available school resources. The selection process at each school varied and was determined by the school. At School 1, the principal designated a fifth grade classroom to participate. All students who returned signed parental consent forms were able to participate; about one-third returned their forms. At School 2, the science teachers determined that students from each of the three fifth-grade classrooms should be included. They asked each of the fifth grade teachers to select students to participate, with the instruction that students of varying abilities should be included. At School 3, as with School 1, the principal selected a single classroom to participate. The teacher selected students who had adequate English skills and who had not participated in the pilot study over the previous summer. This resulted in an imbalance between boys and girls, because several of the girls were either English learners or had participated in the pilot study. In an effort to rectify the gender imbalance at School 3, an additional three girls were recruited from another classroom. One mother asked for further clarification on the nature of the study before she allowed her daughter to participate. Another student said that her father thought mass had to do with church. He wondered why she was studying mass in school, and she explained to him what mass meant in this context. All students who returned signed parental consent forms elected to participate in the study. The ages of the participants were one 9-year-old, thirty 10-year-olds, two 11-year-olds, and one missing value.

Group assignment was done as follows. The "first" subject in each gender and learning preference category was assigned to the experimental group. The order varied by school. At School 1, consent forms trickled in over the several days, so the first students were those who returned their forms first. The first participant volunteered to go first because he did not have safety patrol that afternoon. At School 2, the science teacher determined the order. This was because the fifth grade students rotated through three classrooms and subjects (two per day) in a complex schedule, and study participants were to be pulled only from their science studies. At School 3, students were ordered by the order in which they completed their pretest and LCPC surveys. Table 3 shows the breakdown of participants per school.

Table 3

Number and Gender of Participants by School

Site	Boys	Girls	Total
School 1	4	4	8
School 2	5	6	11
School 3	9	6	15
Total	18	16	34

Research Questions

The following sections will examine the findings as they relate to each of the study questions.

Main Question: Did the Simulation Affect Student Reasoning?

Did working with the simulation affect students' conceptions of gravity, mass, force, and/or motion? In investigating this question, whether children's understandings of the concepts were affected by their work with the simulation, participants' prior knowledge as evidenced by their responses on the pretest and their developing understanding as evidenced by their answers during the interview and posttest were examined and compared. An effort has been made to discuss gravity, mass, force and motion separately, although some overlap was unavoidable due to the interrelatedness of the concepts as experienced within the simulation.

Students' Conceptions of Gravity

Gravity's not going to be fair with us.

–J, a 10-year-old boy

By fifth grade, most students have had some exposure to the concept of gravity. One of the California Science Standards (California Department of Education, 1998) for fifth grade holds that students should know that "the path of a planet around the Sun is due to the gravitational attraction between the Sun and the planet."

It was anticipated that working with the simulation would affect student reasoning about gravity. In a pilot for this study, students often noticed that gravity made the ball heavier and made it move faster.

Prior knowledge. All but one participant indicated some prior understanding of the concept of gravity, though the degree of accuracy varied. Gravity's role in keeping us on the ground or keeping us from floating off into space was most frequently mentioned in the pretest, and was often mentioned again in the interview. A few students expressed some uncertainty about this. One stated that gravity makes us float in space, and another stated that she has a hard time remembering whether gravity keeps us down or makes us float.

Location and effects of gravitational force. Answers were more varied when discussing how gravity keeps us on the ground. During the interview, several students expressed the belief that gravity is a force in the air or atmosphere that pushes down on us, or surrounds us "like a curtain" and holds us down. Of the students who ventured an opinion about the location of gravity for someone on Earth, 6 participants said that it was in the air, while an equal number said that it was in or on the ground. One student stated that gravity is a force pulling us toward the Earth's core. The student who had indicated on the pretest that she did not know what gravity was stated in the interview that gravity "protects us." When questioned further, she said that without gravity, "we would have to go live in the wild."

Gravity and weight. When asked to define gravity during the pretest, one student mentioned weight. During the interview, few students explicitly mentioned a connection between gravity and weight when defining gravity. However, 21 participants connected the two at some point during the experiments or interview, and 7 equated weight with the pull of gravity. During the interview, when asked what they would do to make the ball as heavy as possible, the most common response was some variation of "set mass and gravity to 100" (the maximum setting for both).

Posttest responses. During the posttest, 24 students agreed that the weight of the ball would increase if gravity were increased when asked to identify factors that would make the ball heavier, and 20 agreed that an increase in gravity would make the ball heavier when asked to identify changes that would occur if gravity were increased. Figure 6 shows the frequencies of each posttest item by group and total. The control group, without force feedback, is designated "No FF," and the experimental group is designated "FF." T or F indicates whether the item is true or false. Students were told that they should circle as many answers as they thought were correct.

Gravity and force. During the pretest, the most common example of force given was gravity. During experimentation, the majority of participants noted changes in the amount of force required to hit the ball an equal distance under differing amounts of gravitational force. During the course of the experiments, 21 participants noted that they had to use more force in the high gravity experiments. Force is discussed in more detail later in this section.

Items	T/F	FF	No FF	Total
1. How can you increase the weight of the ball?				
a. Increase the mass of the ball	T	15	12	27
b. Increase the gravity	T	11	13	24
c. Decrease the gravity	F	2	1	3
d. Decrease the mass of the ball	F	2	3	5
2. What affects the speed that the ball falls?				
a. The mass of the ball	F	6	10	16
b. The force of gravity	T	14	12	26
c. The distance the ball falls	T	1	3	4
d. None of the above	F	0	0	0
3. What happens when you increase the gravity?				
a. The mass of the ball increases	F	1	3	4
b. The ball becomes heavier	T	13	7	20
c. The ball falls faster	T	11	9	20
d. The ball falls more slowly	F	0	3	3
4. What happens when you increase the mass?				
a. The ball becomes heavier	T	7	5	12
b. The ball falls faster	F	8	8	16
c. The ball becomes harder to move	T	4	8	12
d. The ball falls more slowly	F	4	4	8
5. What happens when you decrease the gravity?				
a. The ball becomes heavier	F	3	1	4
b. The ball becomes lighter	T	11	13	24
c. The ball falls faster	F	3	5	8
d. The ball falls more slowly	T	11	7	18
6. What happens when you decrease the mass?				
a. The gravity increases	F	3	2	5
b. The ball falls more slowly	F	7	11	18
c. The ball becomes lighter	T	11	8	19
d. The ball falls faster	F	3	3	6

Figure 6. Frequency of posttest responses by group and total.

Summary of gravity findings. By far the most common description of gravity given on the pretest was that it keeps us down or keeps us from floating into space, with 19 participants responding this way. Sixteen participants gave similar responses when asked to define gravity during the interview. During experimentation, participants were likely to notice that increased gravity made the ball heavier and made it fall faster. This can also be seen from the posttest responses in Figure 6. Speed is discussed in detail later in this section.

Taken together from the pretest and transcription data, the most commonly expressed ideas about gravity are shown in Table 4. Topics such as bounce and elasticity are discussed later in this section.

Table 4

Most Common Ideas About Gravity

N	Idea
25	keeps us down, makes things fall
24	(more gravity) makes faster
21	(more gravity) makes the ball heavier
14	(more gravity) makes the paddle hang more
14	(more gravity) makes (the ball) less bouncy
14	force coming down, pulling

Conceptions of Mass

> Well, because I thought mass was how much it takes up space. On this one it's kind of like the weight, I think. Of, like, I think the ball changes its weight because it just goes a lot heavier.
>
> –T, 10-year-old girl

It was not anticipated that many participants would have prior knowledge of mass. Mass as such is not mentioned in the California Science Standards until eighth grade. During a pilot study with 12 students from one of the three school sites, none of them could attempt a definition of mass. In earlier questioning of nine children ranging from grades three to seven, only two could endeavor to define mass, and they were tentative in their responses. One was in sixth grade and the other was in seventh. During the pilot study, students most often noted during experimentation that increasing mass increased weight and caused the ball to bounce more, so it was anticipated that students in the current study would notice these effects. Several students reported that mass affected speed, so it was expected that a similar finding might result from this study.

Prior knowledge. Surprisingly, 23 participants provided a definition of mass. Prior knowledge of mass as expressed on the pretest varied widely among the schools. Probably the most important differences among schools with respect to this study were the students' prior knowledge of the concepts and the fact that School 2 was progressing through their mass unit concurrent with this study. Additionally, School 2 had just completed an astronomy unit in preparation for an "Astronomy Night" event for the school and community. All but one of these students had at least some idea of what mass is; most equated it with any object that occupies space. One student said it is "everything." Others defined it as having great size or weight. One student wrote, "Anything that is matter and takes up space."

In contrast, students at School 1 had not studied mass. All but one of the eight students at School 1 could not come up with a definition of mass on the pretest. One boy thought it had to do with the sail of a boat, mistaking mass for 'mast.' The students at School 3 were somewhere in the middle, with some students having some understanding of mass and others having no idea.

Mass and weight. During the administration of the pretest at School 3, with 12 participants present, one of the students blurted, "I know what mass is. Mass is weight!" Thereafter, all the students present wrote some variant of "mass is weight" as the definition of mass on the pretest. Upon interviewing them individually, some thought they had studied mass before, but others had no prior experience with the concept of mass. One student at first said she was unsure. On reflection, she wondered aloud what she had written on the pretest, deciding that she had put "mass is weight." She had.

Twelve participants defined mass as weight in the pretest. During experimentation, more participants noted a relationship between mass and weight. In all, 26 participants defined mass as weight or said that mass affected weight during their session.

Mass, space, and density. Next to the belief that mass is weight, the most common understanding about mass was that it takes up space; eight participants stated this on their pretest. Most students seemed to relate mass to size but not necessarily density.

M: Mass is anything that has matter.

LB: Okay.

M: Matter (Inaudible) has mass and occupies space. Mass. Mass is how big an object is. How much room it takes up.

A few students seemed to understand that there is more to mass than just occupying space.

E: I would describe mass like how much is mainly in something.

No participants used the word "density," although the next student seemed to allude to it.

J: Mass is almost it's like what how much of it there is. Or no, yeah.

LB: How much of?

J: It's almost like how much it weighs almost.

This student went on to describe a class project in which students compared the mass of two identical containers, one filled with cotton balls and the other with pebbles.

Mass and speed. As happened in the pilot study, some students drew a connection between mass and speed. Twenty-one students indicated by their comments and posttest responses that they believed mass had an effect on speed. Of those, 15 believed that heavier objects fall faster; to illustrate in the words of one student, "I think the mass made it a lot easier to get it to go faster and it would become faster if you did a lot of mass." On the posttest, 16 students agreed that increasing mass makes the ball fall faster, and 18 students agreed that decreasing mass makes the ball fall more slowly.

Fourteen participants said that more mass made the speed of the ball slower; 8 students said at different times both that more mass makes the speed of the ball faster and that more mass makes it go slower. Clearly, there was a great deal confusion around this concept. Speed is discussed in greater detail later in this section.

Perceptions of learning about mass and gravity. Toward the end of the interview, participants were asked if they thought they had learned anything new about mass or gravity. Almost all students thought they had learned something new, for example, "that when you put mass and gravity to a hundred then the ball goes faster and goes, the paddle goes lower."

One student learned that both mass and gravity have an effect on weight.

R: That mass might not always be the heavier thing; it might be gravity. [...]

LB: [...] With mass, you learned that it might not always be the heaviest thing?

R: Yes.

LB: You think that gravity also can make something heavy.

R: Yeah.

In some cases, what they had learned was incorrect. Another participant expressed the common misconception that mass affects speed, "and that gravity's heavy and mass makes it a lot faster."

Summary of findings on mass. During the pretest, the most commonly expressed ideas about mass were that mass is weight or that mass takes up space. During the study, only a few participants expressed an awareness of the concept of density as it relates to mass.

During experimentation, participants again noted the effect of mass on the weight of the ball, but also noted that changes in mass affected the movement of the ball and paddle, particularly with regard to the bounce of the ball, the sag or stretch of the paddle, and the speed of the ball. These concepts are discussed in detail later in this section.

Table 5 shows the most commonly expressed ideas about mass from the pretest and transcription data.

Table 5

Most Common Ideas About Mass

N	Idea
26	makes heavier
25	makes bouncier
16	makes the paddle sag
15	more mass=faster
14	more mass=slower
10	takes up space

Conceptions of Force

The California Science Standards identify standards for force and motion for second graders, so the concept of force should be familiar to fifth grade students. The Standards describe force as a push or a pull.

Prior knowledge. Students provided disparate definitions of force in the pretest. A common response was simply "?" or "I don't know." Two students defined force in the sense of being forced to do something, perhaps against one's will.

> force is like someone is making you do something
>
> example of force: go to your room
>
> force is making someone or something do something
>
> example of force: go take out the trash now

A third student defined it less personally, but still with some sense of will being imposed on an object.

> force makes something do something

example of force: force can make something fall

Two students seemed to understand force as having a protective quality, perhaps like a force field or "The Force" of Star Wars fame, or as in the use of force in an armed sense. As described previously in the subsection on gravity, a third student understood gravity as being protective.

force: like you are perticting [*sic*]

example of force: gravity force

force: it is like a perticion [*sic*]

example of force: it is like you are perticting [*sic*]

However, most students who provided a response discussed force in terms of pushing or pulling. Some examples follow.

force is the pull on an object

example of force: when you play tug of war

force: the push of an object on another

example of force: a car crash

force is something that can push something

example of force: waves

Two students described force as having strength.

force is some kind of strong object

example of force: wind

force is something that pushes something with great strength

example of force: someone flying something in a catapult or something else.

The most common examples of force given were gravity examples, perhaps because the children had been prompted by the question that asked them to define gravity, and they knew they would be doing and investigation of gravity and mass.

force: force is some caned [*sic*] gravity

example of force: gravity is some force

force: gravity

example of force: gravity. It keeps you on the ground

force is like something that keeps the planets in orbit

example of force: force is like the force of gravity

Force in the experiments. In each of the four experiments, students were asked to describe how hard they hit the ball. From these questions, a number of concepts arose regarding force. These codes are included in Appendix C. The codes for actual force used (hit the ball hard, didn't hit hard) were kept separate from the codes for perceived need for force (need to hit it hard, don't have to hit as hard) because participants would sometimes hit the ball really hard to see how far it would go, even though they did not perceive that they needed to hit it hard. Twenty-three students expressed that they needed to hit the ball hard or very hard when the gravity was high. Fourteen noticed that how far the ball went was determined by how hard they hit it with the paddle. Twelve noticed that when they hit the ball hard and it went far, it was traveling faster when it finally returned. The students were asked to decide whether they had to hit the ball as hard in relation to other experiments to get the ball to go the same distance. Most identified experiment 3 or 4 (high gravity) as requiring the most force.

Summary of findings about force. While prior knowledge varied, the most common responses to the question, "Define force:" were "?," a push or a pull, and gravity. During experimentation, students responded to varying degrees of mass and gravity by indicating changes in amount of force required.

Table 6

Most Common Ideas and Definitions of Force

N	Idea
25	I hit it hard
23	I need to hit it hard
20	The ball is harder to move
17	I don't have to hit as hard
14	Amount of force controls distance of ball
12	Amount of force controls speed of ball
10	Definition of force: ?
8	Definition of force: a push or a pull
5	Definition of force: gravity

Conceptions of Motion: Speed and Acceleration

> Oh, my God! This is really, really fast.
>
> –C., 10-year-old boy

As mentioned previously with regard to force, the California Science Standards identify standards for force and motion for second graders. According to the Standards, students should know that the amount of change in the motion of an object is related to the amount of force on the object.

Speed in the experiments. In each of the four experiments, participants were asked to describe how fast the ball was moving. Since the two low gravity experiments were first, students would sometimes say that they appeared fast, but then when they conducted the high gravity experiments, they would say these were “really, really fast” or even faster than before. This ordering of the experiments likely accounts for some of the difference in the number of students who said the experiment was moving fast versus slow (32 to 23).

Many students noted that increased gravity caused the ball to go faster, but others made a distinction between the speed of the ball when it was going up and the speed when falling, often describing the upward speed as slow and the downward speed as fast. This was sometimes reversed for low gravity conditions, as the ball required much less force to launch it, but then fell at a lower rate of acceleration. Mass was often described as affecting speed, as previously discussed.

Several participants reasoned that the ball traveled far when it was gone from view for a long time, and some, like the following student, reasoned that the amount of force and the distance traveled affected the speed of the ball.

> K: So if you want it to go fast you have to hit it high and hard. Then if you want it to go slow you would hit it just like a little bit.

Posttest results. On the posttest were several items that queried about the relationship of mass or gravity to speed, and question 2 specifically asked, “What affects the speed that the ball falls?” Twenty-six participants answered “the force of gravity” in response to this question, and sixteen answered “the mass of the ball.” Figure 6 gives the frequency of posttest responses for all items.

The word “speed” was used on the posttest instead of acceleration because of the level of the students, and because the overall speed (total time elapsed) of the high gravity experiments were dramatically shorter than the low gravity experiments due to the greater rate of acceleration.

Summary of findings about speed. Participants were most likely to relate changes in gravity to changes in speed, although mass was often identified as affecting speed as well. Table 7 shows the most commonly expressed ideas about speed during the experiments from the transcription data.

Table 7

Most Common Observations of Speed

N	Observation
32	Fast
23	Slow
21	Faster coming down
17	Takes long time to come back
12	Goes up faster
12	Slower going up
10	Ex. 4 is fastest (high gravity)
10	Slower coming down
8	Ex. 3 is fastest (high gravity)

Speed was probably one of the more difficult concepts for students to describe clearly because of changing force, velocity, and the effects of elastic force.

Conceptions of Motion: Bounce, Elastic Force and Inertia

In the simulation, one of the most noticeable affects of changes in mass has to do with the number of times the ball bounces. A very massive ball pushes down on the paddle until it is quite bent. At that point, the elastic force of the distended paddle shoots the ball upward with great force. When the gravity is low, this elastic force keeps the ball bouncing for a long time. If the gravity setting is high, this force will stop the bouncing more quickly. When the ball has little mass and inertia, the resultant elastic force of the paddle is negligible, and the ball does not bounce very times, particularly if the gravitational force is high.

Experiments. In each of the four experiments, students were asked to bounce the ball to the top of the screen, then hold the paddle still and count the number of times the ball bounced. Most students discovered that experiment 2 (high mass and low gravity) resulted in the most bounces, and that experiment 4 (low mass and high gravity) resulted in the fewest bounces. Twenty-five students were able to take this further, reasoning that the more massive ball bounces more. Fourteen participants reasoned that more gravity made the ball bounce less. The effect of mass was probably more obvious, though both mass and gravity affected the number of bounces. The distortion of the paddle by the massive ball increased elastic force of the paddle and caused the ball to keep rebounding. This elasticity of the paddle also caused the ball to keep wiggling the paddle for a long time, even though technically it was not leaving the paddle.

Inertia. Some students noted that the ball was harder to "budge" when the mass was increased, or that there seemed to be a hesitation, even when the gravity was low and therefore the ball was not at its heaviest. Others described the downward push of the heavy ball onto the paddle that resulted in the upward force that kept it bouncing. One student described this as the result of displacement by a massive object; the "circle thing" she referred to is a trampoline.

W: Yeah, mass I think and what mass is something that takes up the space.

LB: Okay.

W: And if you would have mass, then if you only have gravity then you would go faster but if you have mass then you would like if you'd go up to the circle thing when you go up and jump. If you only have gravity then it would like, you would go faster but not like bouncy. But if you have mass then it would be really bounce because you take up the space of the circle thing.

LB: Uh-huh. Okay. So you're pushing on the thing with your mass and so it makes it more bouncy.

W: Yeah.

Summary of findings on bounce, elastic force, and inertia. The majority of participants noticed that the ball bounced more when mass was high, while fewer noticed that gravity decreased the number of bounces. Taken from the transcription data, the most commonly expressed ideas about bounce and elastic force during experimentation are shown in Table 8.

Table 8

Most Common Ideas about bounce, elastic force

N	Observation
25	Mass makes it bouncier
23	It is bouncy
20	Not very bouncy
16	Ex. 2 is the bounciest (high mass, low gravity)
15	Elastic force (bends, then pushes up)
14	Gravity makes it less bouncy
11	Ex. 4 is least bouncy (low mass, high gravity)

Conceptions of Weight

Weight is an important concept that is integral to an understanding of mass and gravity. Students study weight beginning in kindergarten, but not necessarily in conjunction with gravity and mass by fifth grade. In the software, feedback regarding changes in weight is shown visually by the bending of the paddle. In the experimental group, increased force feedback also serves to emphasize changes in weight.

Weight in the experiments. Many of the participants discussed weight changes in the ball as a result of mass or gravity changes. Some posttest items addressed changes in weight as a result of changes in mass or gravity. Students who had previously learned that 'mass is weight' tended to use that definition for mass in the interview as well as the pretest. Yet, when asked to define weight, most students were stumped. A typical response was, “weight is how heavy someone or something is.” When asked whether mass or gravity had anything to do with weight, student answers varied, but some students remained uncertain or answered negatively. When asked how to make the ball as heavy as possible using the software, 15 students said to increase both mass and gravity. Maximum mass and gravity is equivalent to experiment 3. Of students who had studied mass, some said to increase mass but not gravity. Others said gravity, but not mass, affected weight.

Posttest results. On the posttest, the first question asked, “How can you increase the weight of the ball?” Twenty-seven participants selected “increase the mass of the ball,” and 24 selected “increase the gravity,” with 18 selecting both answers. Other posttest items included answer choices regarding the relationship of mass or gravity to weight. Twenty students agreed that an increase in gravity makes the ball heavier, 12 agreed that increasing the mass makes the ball heavier, 24 agreed that decreasing gravity makes the ball lighter, and 19 agreed that decreasing mass makes the ball lighter. Frequencies for all posttest items are given in Figure 6.

Summary of findings about weight. During the experiments, interview and posttest, most participants related changes in weight to changes in mass, gravity, or both. Table 9 shows commonly expressed ideas about weight from the pretest and transcription data.

Seven participants or about one-fifth indicated some understanding that weight is gravity or is similar to gravity. When asked to define weight, one student said, “[...] like the pull of gravity, like how much the pull of gravity on an object is.”

Table 9

Common Observations About Weight

N	Observations about weight
27	Ball is heavi(er)
26	Mass makes the ball heavier
21	Gravity makes the ball heavier
15	Ball is light(er)
15	Maximum mass and gravity creates the heaviest ball
12	Weight = mass
10	Causes paddle to sink
8	Ex. 3 is heaviest
8	Ex. 4 is heaviest
7	Weight equals the pull of gravity

Use of Metaphor and Analogy in Student Reasoning

Most students relied to varying degrees on metaphor and analogy to describe the behavior of the simulation during the experiments and interview, with 23 participants making at least one such connection and a few making several references to real things or situations. In describing the actions and attributes of the simulation, students often used comparisons to real objects or games that shared similar traits. The behavior or attributes of the ball under differing experimental conditions was compared to those of various kinds of real balls: plastic, ping-pong, basketball, pool, and so on. The most common comparisons to the actions of the simulation were “like a slingshot,” “like a trampoline,” and “ping-pong.”

J: It's like a trampoline.

LB: Okay. What makes it like a trampoline?

J: Because every time I bounce it hard it doesn't go that high.

LB: Okay.

J: And every time it lands on it, it keeps on (inaudible). It's bouncing a lot like that.

Some metaphors implied volition on the part of the simulation. The ball and paddle were sometimes described as having wills of their own; for example, the ball doesn't want to go away from the paddle, or "the ball is not letting the paddle to hit it."

A couple of participants in the experimental group used metaphor to describe haptic feedback.

J: It feels like it's trying to force me to go back into my hole. Like a hole.

J: It feels like I need to move a hundred pound cat.

W: I can see that it kind of sticks to the paddle. Like for example with this one it feels like a real ball. And if you have something like a rubber band and a marble in it and it would first it would stick a little bit then go up.

Metaphor can be a useful tool when trying to understand something unfamiliar; if carried too far it can foster misconceptions.

Reasoning and Math Connections

Almost half of participants indicated the belief that there is some sort of balance or equation relationship between mass and gravity, with "equal" mass and gravity often preferable. In the following example, it seems that there is a belief that mass and gravity cancel each other with regard to speed.

J: Okay, it doesn't go as fast as mass is a 100 cause the mass cancels speed, but since the gravity is 5, it makes goes a little faster, so it's kind of like, 55% fast kind of. I guess.

In this example, an equal "amount" of mass and gravity make the speed faster.

E: Maybe I think, it was faster because it had the same amount of mass as the gravity.

In the next example, there is a sense of shared effort on the part of mass and gravity.

J: Then the gravity will be more powerful than the mass.

LB: Okay.

J: And the mass it just does a little bit of work while the gravity does everything else.

LB: Okay.

J: And if the mass is up higher than the gravity then the mass is the one doing all the work instead of the gravity.

LB: So do you see them as kind of balancing each other or they're kind of, I'm trying to figure out how you think they're working together?

J: Because like if the gravity and mass are to a hundred then it hangs down because of gravity.

LB: Because it's hanging a lot.

J: And because the mass and the gravity they're like trying to make the ball hang.

LB: Okay.

J: And if the gravity is set to a hundred then the gravity will have advantage of the ball.

A few participants expressed the belief that mass and gravity are opposing forces, for example, that mass causes the ball to come down and gravity causes it to float upward. In the next example, the participant saw mass and gravity as opposing forces controlling the weight of the ball.

R: It was a lot heavier. So I think that it's gravity that makes it heavy and mass that makes it lighter.

In the next instance, equal mass and gravity are thought to be better than unequal mass and gravity.

W: Yeah, that's right. You have a lot of gravity and it would be better if you have the same but equal size of the mass and gravity that they would be a lot because then if you have more gravity then it would come faster. And go down fast. So it would have a lot of gravity, but if you oh. It would be better, better if you have the equal size, no it's not size but equal how do you call that, equal size, yeah, equal size of mass and gravity.

When questioned further, she thought it was better because she expected that the ball would bounce more, and she liked that.

Units of Measurement

Aside from the issues of equality, a few participants used inappropriate units of measure or math concepts when reasoning about mass and gravity. In the following example, the participant seemed to be discussing varying temperatures of mass and gravity.

A: So, what I would say about the first question, about how to make a rule that fit in the number of bounces, I would say that it depends on the mass and the gravity temperatures.

A: Yeah. I was looking at the gravity to see if they had high gravity, but I guess they don't. So they have low mass, and different degree in gravity. (Inaudible) experiments two and three, they both have high mass, and different degree in gravity. This time you can feel something.

In the following example, the student seems to be making odds on the speed of the ball.

R: Like a 50/50 chance. It's either slower or faster but I say it's in the middle.

The software controls for gravity and mass are identically numbered on a scale from 5 to 100. This was likely a factor in the tendency of some students to see them as equal or unequal amounts.

Making Connections to Prior Knowledge

Prior knowledge had an effect on reasoning and how participants interpreted their experiences with the simulation activities. In previous sections, there has been some discussion of the tendency of some participants to recall prior knowledge and disregard their experimentation with the simulation when asked to define terms during the interview, even though they had just completed an activity wherein they exhibited increased understanding of the concepts in question.

LB: So first of all, what is mass?

J: Mass? The weight.

LB: The mass is the weight. The weight of...?

J: The ball.

The following example is from a participant who had previously studied mass, but had forgotten momentarily.

LB: So first of all, have you studied mass before in school, ever or not really or…?

Y: Yeah.

LB: You did study it? Do you know what grade you were in when you studied it?

Y: I think in fourth.

LB: Okay. And so what is mass?

Y: When it comes down it's like heavier.

LB: Okay. And so you think the ball like in this program the ball would be heavier? Is that what you're thinking? (Y: yeah) Okay. Oops. And what is gravity?

Y: Gravity, oh like this, is I forgot! Mass is like the big thing maybe?

On the pretest, this student had defined mass as "like a big round thing." So it seemed that she first recalled her experience with mass in the simulation and then recalled her definition of mass from memory.

Participants who had no prior knowledge of the concept could only reflect on their immediate past experience to formulate a response, so their answers tended to be specific to the simulation experience.

LB: Okay? Okay so first of all I'm wondering, did you say you've studied mass before at all?

N: No.

LB: No? Okay. What do you think mass is, after having done this?

N: Well I think mass is what makes it...heavy, I think.

LB: Okay.

N: Mass, if you like put it really high, it's really heavy.

Some students were able to recall prior knowledge if prompted, and conversely, participants who recited rote definitions of concepts like mass could draw upon their experiences with the simulation when asked specifically to reflect upon it.

Main Question: Did Force Feedback Affect Student Reasoning?

Does force feedback affect students' conceptions of gravity, mass, force, and/or motion? Force feedback provides additional information about the changing effects of mass and gravity on the state of the simulation, but it can also distract the participant's attention from the visual information display. Much of the essential feedback within the simulation can be discerned by the visual sense alone. For instance, most participants indicated either verbally or by posttest responses that they had concluded that the ball changed weight under different simulation conditions, regardless of whether they were in the control (No FF) or experimental (FF) group. An important question is whether the positive effects of force feedback outweigh the potentially negative effects.

The posttest questions, shown in Figure 6, were perhaps somewhat unusual in that participants were to select as many answers as addressed the question. That is, it was not simply multiple choice, but multiple answer and multiple choice. Participants were given written and verbal directions that they should circle all the correct answers. There were totals of 11 correct items and 13 incorrect items possible on the posttest, as all but one of the six questions had two correct answers.

Initially participants were given a score for the number of correct items they selected and a separate score for the number of incorrect items they selected. In analysis, this sometimes led to a significant difference between groups in the number of correct answers but not incorrect answers, or vice versa. Subsequently, a point score was assigned for each of the 24 answers. One point was given for a correct response, meaning that it had been selected if it were correct and had not been selected if it were incorrect. A score of zero was awarded if the answer was correct and not selected or if the answer was incorrect and was selected. This means the scoring was done essentially as if it were a true-false quiz. A score from 0 to 24 was possible; among these participants, the lowest score was 10 and the highest score was 22.

Table 10

Correct, Incorrect and Total Posttest Descriptive Statistics

	N	Minimum	Maximum	Mean
Correct selected	34	2	10	6.09
Incorrect selected	34	0	7	2.76
TOTAL (all items scored)	34	10	22	16.2353

Tables 11 and 12 show that posttest scores of subjects in the experimental or force feedback (FF) group were slightly better than those of the control or no force feedback (No FF) group when using the separate correct and incorrect scores. They had both more correct responses (though not significantly so) and significantly fewer incorrect responses.

Table 11

Posttest Correct Scores by Treatment Group

Group	N	Mean	*t*	*df*	*p*
FF	17	6.47	1.059	32	.297
No FF	17	5.71			

Table 12

Posttest Incorrect by Treatment Group (lower is better)

Group	N	Mean	*t*	*df*	*p*
FF	17	2.35	-1.877†	32	.070
No FF	17	3.18			

†*p*=.1, two-tailed.

When the 24-point scale posttest scores were analyzed, there was a near significant difference between the two groups.

Table 13

Posttest Total Scores by Treatment Group

Group	N	Mean	*t*	*df*	*p*
FF	17	16.9412	1.595	32	.121
No FF	17	15.5294			

Next, the participant scores were divided into two groups, those above and below the mean of 16.2353. As posttest scores were given in whole numbers, the High scoring group had posttest scores ≥ 17, and the Low scoring group had posttest scores ≤ 16. There were 19 in the Low group and 15 in the High group. A crosstabulation count of High and Low groups by FF and No FF groups in Table 14 shows that 10 FF group participants were in the High scoring group compared with 5 No FF group participants in the High scoring group. A Pearson Chi-square test showed a significant result (X_2=2.982, *df*=1, *p*=.084).

Table 14

Crosstabulation of Posttest Score by Treatment Group

	Low	High	Total
FF	7	10	17
No FF	12	5	17
Total	19	15	34

After the scores as a whole were analyzed, the four items for each question were grouped and a total score based on a 4-point scale was computed for each question. Each item was also analyzed individually. Of the six questions, the only scores that showed significant differences between the groups were those for Question 3, which asks: "What happens when you increase the gravity?" The FF group scored significantly higher on Question 3, with *p*=.011 (Table 15).

Table 15

Question 3 Scores by Treatment Group

Group	N	Mean	*t*	*df*	*p*
FF	17	3.3529	2.689*	32	.011
No FF	17	2.5882			

**p*=.05, two-tailed.

There were significant differences between the groups on two of the four individual items under Question 3. On the first item, 3b, significantly more participants in the FF group agreed that increasing gravity makes the ball heavier with 13 in the FF group and 7 in the No FF group *t*=2.173, *df*= 31.318, *p*=.037).

Table 16

Item 3b by Treatment Group

Group	N	Mean	*t*	*df*	*p*
FF	17	.76	2.173*	31.318	.037
No FF	17	.41			

**p*=.05, two-tailed.

The second item, 3d, was the false statement that increasing gravity makes the ball fall more slowly. This was a significant result, though the number was small (Table 17). Fewer than 10% of participants agreed with this statement; none in the FF group and 3 in the No FF group.

Table 17

Item 3d by Treatment Group

Group	N	Mean	*t*	*df*	*p*
FF	17	1.00	1.852†	16.000	.083
No FF	17	.82			

†*p*=.1, two-tailed.

The frequency scores for individual posttest items (Figure 6), while not statistically significant, show a few interesting differences between the FF and No FF groups. Fewer in the FF group agreed that mass affects the speed that the ball falls (6 in the FF group and 10 in the No FF group). While equal numbers (8 in each group) agreed that increase mass makes the ball fall faster, 7 in the FF group agreed that decreasing mass makes the ball fall more slowly, compared with 11 in the No FF group. 11 in the FF group agreed that the ball falls more slowly when gravity is decreased, compared with 7 in the No FF group. And interestingly, more in the No FF group (8) agreed that increasing mass makes the ball harder to move compared with 4 in the FF group. It was supposed that force feedback would make it easier to tell that the ball was harder to move, but it did not in this case.

During the experiments, 12 in the FF group and 8 in the No FF group described the ball as harder to move. More of these were in reference to the higher gravity experiments, but 4 in the FF group and 2 in the No FF group described Experiment 2 (the high mass-low gravity experiment) as harder to move.

When asked what mass referred to in the software, 11 respondents (7 in the experimental group, 4 in the control group) thought that mass referred to the ball, but 4 (3 in the control group) thought it referred to the paddle. One of the respondents in the experimental group stated that mass had to do with the force or weight of the ball or paddle. The following example illustrates how one student reasoned that the weight of the ball remained the same, but the stiffness of the paddle decreased when mass increased.

T: Or yeah how much mass it has in it. Or how light the paddle was, like the ball could be normal but the paddle could be.

LB: The paddle was?

T: Like light. Really light. And then it just bends (inaudible).

LB: Okay. Okay. And if you were going to make the ball weigh as much as possible, how would you set the mass and gravity?

T: Oh on like really heavy, like make the ball really heavy? if I didn't want it to get really heavy and drop something like that?

LB: If you just wanted to make it as heavy as you possibly could. If somebody said make a really heavy ball how would you do that?

T: I'd make I probably make the mass down to like five because (inaudible). It just doesn't bounce but then the gravity would stay there so it would stay on better. Like that if when you stiffer to hold the ball. Then...

LB: You mean if the paddle's stiffer?

T: Yeah if the paddle's stiffer then the heavy ball won't like fall. If you made the mass go down. Like when the paddle went down really deep.

LB: Uh-huh. When do you think the ball... so when it is going down, do you think the ball's heavy then? When the paddle's bending down, do you think that's a heavy ball?

T: Yeah.

LB: Is that heavier than when the paddle is straight?

T: I think they're kind of the same it's just that yeah the mass gets stiffer a lot. And it holds the heavy ball.

LB: Okay.

T: Like the ball weighs the same thing.

LB: Okay. So the mass has to do with the paddle?

T: Yeah.

This subject was in the control group, so she was unable to feel the changes in weight that accompanied the changes in mass. If she had been able to feel weight changes, it is likely she would not have concluded, "the ball weighs the same thing."

During their interaction with the simulation, the participants in the FF group commented on how things felt as well as looked. For example, they noted whether the ball felt lighter or heavier, or pushed harder or softer. Some also expressed pleasure in the way that it felt.

H: Oooh, this one feels better.

LB: Feels better?

H: Actually it feels good.

Interestingly, those who expressed pleasure in the way it felt had a mass setting of 50 or 100 and a gravity setting of 5.

Participants in both groups expressed unanimous approval of the experience when asked whether or not they enjoyed it, with "cool" being the most frequently used word to describe it. However, the FF group was more given to spontaneous outbursts of approval during the course of the experiments.

> C: Oh. Not that heavy. Whoa this is cool. Did you get this program from the Internet?
>
> J: Well, this is the first time I've ever felt something on a computer. It's weird. It's pretty cool, too.

When asked to explain what they liked about it, some in the FF group identified the way that it felt.

> C1: Because the, it yeah it feels like pretty cool once you change the mass and gravity.
>
> C2: I liked it because it was cool to feel the ball bouncing.

Some of the drawbacks or potentially negative effects of force feedback noted by the participants were fatigue, "hand feels weird" from the vibration, and the necessity of holding the paddle while bouncing the ball. Without force feedback, participants could simply set the paddle in the path of the ball and watch it bounce. Because of this, full attention could be paid to the visual display rather than to monitoring the equipment, and accidental mouse bumps while the participant was attempting to count bounces could be avoided. With force feedback, the paddle would be knocked to the bottom of the screen when the ball struck if it was not held in place. Several participants explored this feature with evident enthusiasm.

Question: Is Force Feedback More Effective for Some Learners?

Does the effectiveness of force feedback vary depending on the subject's modal learning preference, gender, or prior knowledge or experience? To investigate this question participants' data were examined qualitatively. They were analyzed quantitatively if there were sufficient subjects in the subgroups being examined.

Modal Learning Preference. Modal learning preference was assessed prior to participation with the Learning Channel Preference Checklist (LCPC), a 36 item, 5-point Likert-scaled survey instrument. The participants were scored on their visual, auditory, and haptic preferences based on their responses to the survey questions. According to the scoring instructions, a two-point difference is enough to differentiate a preference, whereas a one-point difference is not.

As shown in Table 18, modal preference was not evenly distributed among the participants; the overwhelming majority had a visual preference, and only one participant had a clear haptic preference.

Table 18

Modal Learning Preference Frequency

Preference	Frequency	Percent
Visual	21	61.8
Visual/Auditory	5	14.7
Visual/Auditory/Haptic	1	2.9
Auditory	5	14.7
Haptic	1	2.9
Haptic/Visual	1	2.9
Total	34	100.0

Because of this, it was not possible to address the question of whether the haptic learners benefited more from force feedback. However, in interacting with the single haptic learner during the experiments and interview, he sometimes required prompting to direct his attention to visual feedback; he seemed to be more focused on the force feedback than most participants were.

LB: So you're all set. And we're just gonna go ahead and do the same things you've already done, so go ahead and you know bounce it and see how it's acting, how it's changed and how it's the same.

C: Oh. It's kind of hard.

LB: Huh?

C: It's kind of hard.

LB: It's hard to push?

C: (inaudible).

LB: Harder to push it. Okay.

C: (inaudible).

LB: It went pretty far though, too, right?

C: Well it's really hard. It's (inaudible)

LB: You feel it?

C: Yeah.

LB: Yeah?

C: So yeah mass is, mass I think is like the weight.

LB: The weight of it?

C: Yeah.

LB: Okay.

C: And I'm pretty sure that's what I wrote in the other paper too.

LB: Probably did. I think that's what everybody wrote. [...] What do you notice when it's hitting? What's it doing now? It looks a little different, doesn't it.

C: Yeah. It's like when it bounces it's a little bit higher.

LB: It's bouncing higher once it bounces, yeah.

C: Yeah.

LB: And do you think you have to hit it as hard as you did the last time or? Is it different? Or is it about the same? To make it go as far, do you think you have to hit it…?

C: I have to hit it a little bit harder.

LB: Harder? Okay. Okay. And do you think it's moving about as fast, would you say? Or is it different? It seems like it's…does it still seem like kind of slow or does it seem...?

C: It seems...

LB: Faster or slower?

C: Pretty, pretty slower because it has more weight in it and so when it bounces it's like trying to pull me down.

Reasoning that the ball is moving slower because of the perception that it weighs more was an unusual response, but since he noticed that it was pulling down, he may have meant that it was slower going up.

The information provided by the simulation is predominately visual, aided by haptic feedback in the experimental group, so either treatment could be seen as advantageous to those who expressed a visual preference. Conversely, neither treatment would seem especially advantageous to those who had expressed an auditory preference. Comparing the mean scores of the participants with a visual preference with those with an auditory preference, the visual group outperformed the auditory group on some measures. A two-tailed *t*-test showed a weak difference between the two groups on the total posttest scores (t=1.477, df=24, p=.153). Since the interview portion would seem to possibly favor those with an auditory style, the transcripts were reviewed with that idea in mind. However, the auditory learners did not stand out as being particularly strong during the interview. The ability to use visual (and in some cases, haptic) feedback to draw conclusions seemed the more important factor, even in the interview portion.

Table 19

Posttest Total Scores by Visual and Auditory Preferences

Preference	N	Mean	*t*	*df*	*p*
Visual	21	16.6667	1.477	24	.153
Auditory	5	14.6000			

However, those with a mixed visual-auditory preference did as well on average as did those with a visual preference (Table 20). Those with a visual or visual-auditory preference had significantly higher total posttest scores than those with other preferences (*t*= 2.253, *df*=32, *p*=.031, two-tailed).

Table 20

Posttest Total Scores by Visual and Visual/Auditory Preferences

Preference	N	Mean	*t*	*df*	*p*
Visual	21	16.6667	-.416	24	.681
Visual/auditory	5	17.2000			

Dividing those with a visual preference into FF and No FF groups and analyzing posttest scores, the FF group means were 7.09 correct and 2.27 incorrect. The No FF group means were 5.90 correct and 3.20 incorrect. There was a significant difference between groups on posttest incorrect scores (*t*=-1.897, *df*=19, *p*=.070, two-tailed). Comparing the total posttest scores, the FF group still performed better. Mean scores are shown in Table 21. A two-tailed t-test showed a weak difference between the two groups.

Table 21

Total Posttest Scores for Visual FF and No FF Groups

Group	N	Mean	*t*	*df*	*p*
FF	11	17.5455	1.586	19	.129
No FF	10	15.7000			

Gender. Little difference was evident between girls and boys in their interaction during the experiments and interview. The most obvious difference between genders was the use of language by a handful of individuals. A couple of boys used comparisons to weapons to describe the simulation, such as: like a bomb, like being shot at, like a torpedo. On the other hand, girls were more likely to describe aspects of the simulation as having free will or behaving like people or animals:

> K: Like it doesn't want to go far, it just wants to like a cub and its mom they don't want to get separated. They want to stick next to each other so like the ball and the paddle don't want to go away from each other.

Some boys and girls asked to try the controls for damping and stiffness in the simulation to see what they would do. They were told that they could try these controls after they had completed everything, since it would be confusing to introduce more variables in the middle of the session. Most of the students were satisfied with this, but a couple of the boys were extremely persistent. One asked several times if he could try it *now*. In the end, he could only be dissuaded by closing the laptop until he had completed the posttest.

On the posttest, boys' mean score for the number of correct responses was slightly higher than that of the girls. A two-tailed *t*-test found no significant difference between the two groups (Table 22). Other posttest measures were similarly insignificant.

Table 22

Posttest Correct Scores by Gender

Gender	N	Mean	*t*	*df*	*p*
M	18	6.33	.713	32	.481
F	16	5.81			

To reiterate, the gender differences were observed in just a few individuals. Among the majority of participants, gender differences were not apparent.

Prior Knowledge or Experience. As was previously discussed with regard to the first research question, prior knowledge affected student reasoning, both positively and negatively. Participants' prior knowledge varied widely, and was particularly evident with regard to mass. It is useful to examine the effect of prior knowledge by school, because there was wide variance among the three sites with regard to student knowledge of the key concepts. Students at School 1 had not previously studied mass; only one student attempted to define mass, mistaking mass for mast and writing "a sail" as his definition. Students at School 2 were studying mass concurrent with this study. They also had a brief refresher on the solar system in preparation for their school-wide Astronomy Night event, and so had an opportunity to revisit planetary motion. As previously discussed, all but one of the School 2 participants provided a definition for mass. At school 3, students' prior knowledge fell between the extremes; some students had studied mass and others had not. Table 23 shows the mean correct posttest scores for students at the three schools. A two-tailed *t*-test of the difference between mean correct scores for Schools 1 and 2 showed a significant result ($t = -1.960$, $df=17$, $p=.067$).

Table 23

Posttest Mean Correct and Total Scores by School

School	N	Mean Correct	Mean Total
1	8	5.25	15.1250
2	11	6.91	17.4545
3	15	5.93	15.9333

Table 24 shows the mean total posttest scores for students at the three schools. A two-tailed *t*-test of the difference between mean total scores for Schools 1 and 2 showed a significant result (t= -1.906, df=17, p=.074).

Regarding computer availability, Table 24 shows that 32 subjects had a computer at home. One student indicated that she did not have a home computer, and another indicated that her home computer was broken, but for most participants the lack of a home computer was not an issue. This was of interest, because participants varied widely with regard to socio-economic status.

Table 24

Number of Students with a Home Computer

	Frequency	Percent
No home computer	1	2.9
Have home computer	32	94.1
Broken computer	1	2.9
Total	34	100.0

School computer availability was below average for all three schools, with 5.3 given as the statewide average number of students per computer, according to the California Department of Education's *DataQuest* database (2004). Comparing Table 25 computer data with Table 23, the relative availability of school computers correlates with higher posttest scores by school and degree of prior knowledge.

Using the percentage of students who are eligible for free and reduced price meals as a proxy for socio-economic status (SES), it can be seen by comparing Tables 23 and 25 that posttest scores did not correlate with school SES. Individual SES data were not tracked.

Table 25

School Lunch and Computer Data for 2002-2003

School	Free and reduced price meals	No. of Computers per School	No. of Students per Computer
School 1	158 (35.5%)	25	17.8
School 2	15 (2.7%)	71	7.9
School 3	546 (88.8%)	59	10.4

Question: Is Force Feedback More Satisfying for Some Learners?

Does the subject's satisfaction with the treatment vary depending on the subject's modal learning preference, gender, treatment, or prior knowledge or experience? Is haptic feedback motivating for the target population? Regardless of group assignment, gender, learning preference, prior knowledge, or experience, the students were overwhelmingly positive about the experience. They all "liked it", typical responses were because it was "fun," "cool," and "like a game." Almost all of the participants thought they had learned something from the experience.

> A: I thought it was fun. Because since I like science and I'm getting to learn more about science and it's not like a boring way that the teacher teaches us in class. Not that they are ever boring or anything, but and I'm playing a game and actually learning something.

As discussed previously, participants in the force feedback group were more likely to spontaneously exclaim, but there were not enough instances to analyze by demographic attribute.

Participants were asked what kind of software they would design, if they could make any kind of software that they wanted. Those in the FF group were asked for ideas that incorporated force feedback. No two responses were alike, but some topics were: more mass and gravity, horses, machines and friendly robots: "but not killing ones, though," feeling forces in sports, feeling forces with construction tools, music, dance, math, computers and the Internet. While not strictly a software design idea, one student wanted to lobby the president for universal WFFMs:

W: I would make a talk to Presidents that every people would get this these mouse very cheap and (inaudible). And I would make a program for every computers and so people can study how they work and students can get a better grade about it.

LB: Okay.

W: And it's like a game, it's fun.

Summary of findings about motivation. There was no significant difference between the FF and No FF groups in post survey responses of satisfaction. All but two participants in the No FF group answered "yes" to the question, "Did you enjoy this activity?" One responded "not sure." The other had skipped the back page of the posttest.

During the interview, all 34 participants stated that they liked the activity and gave various reasons, some of which are described above. Five participants specifically identified the haptic effects as the reason they liked the experience, but every participant identified something that they liked about it.

Participants in the experimental group were intrigued by the technology as evidenced by their questions and comments. This was partly to do with the fact that they had never seen anything like this before, and partly to do with the sensations generated in response to changing variables in the software.

Any differences in satisfaction, motivation and enjoyment between the two groups were subtle, a matter of degree rather than simply liking or not liking the activity. This perhaps could have been measured with a 5-point Likert scale of satisfaction rather than the "yes," "not sure," and "no" responses provided.

Question: Does Game Experience Matter?

Is there a difference among subgroups based on prior game experience or force feedback experience? How often the participants played video or computer games, and how often they played games with force feedback were not related to how well they performed on the posttest. Mean total posttest scores are shown in Tables 26 and 27. The overall differences were not significant.

Table 26

Frequency of Game Play and Mean Posttest Score

Game Play	N	Mean
Daily	11	16.9091
Weekly	8	16.1250
Once in a while	11	16.0909
Never	3	14.6667

Table 27

Frequency of Force Feedback Game Play and Mean Posttest Score

FF Game Play	N	Mean
Daily	8	15.8750
Weekly	7	16.2857
Once in a while	11	15.7273
Never	8	17.2500

Summary

These findings indicate some positive effects of simulation and force feedback on the acquisition of key concepts by the study participants. Force feedback seemed particularly effective with regard to understanding the effects of an increased gravitational force. Force feedback was not shown to be either more or less effective for subgroups based on gender, modal learning preference, or socio-economic status. All children indicated that they enjoyed their participation, and those in the experimental group were enthusiastic about the force feedback technology.

Chapter 5: Discussion and Recommendations for Further Research

The purpose of this study was to investigate whether work with a software simulation affected children's reasoning about mass, gravity, and related concepts. Further, this study was designed to examine whether students who used the simulation with force feedback differed in their reasoning from students who used the simulation with visual feedback alone. Prior research with adults has shown some positive benefits from the use of haptic feedback in learning situations. This study was conducted with 34 fifth-grade students from three schools. As previously discussed, little prior research exists that addresses the effect of haptic feedback on children's reasoning.

Summary of the Study

Students' participation in the study consisted of the following. First, each participant completed a pretest and survey concerning prior experience with key concepts, computers, and video games. They also completed a learning style preference survey. Following this, each participant was called from class individually to work with the simulation. Each participant followed and completed a guided inquiry worksheet while conducting a series of four experiments. Following the experiments, students generalized rules about the relationships of the variable mass and gravity to concepts such as speed. Next, participants responded to interview questions about key concepts and made predictions about the outcomes of two experiments. Finally, they completed a posttest and attitude survey.

The software used in the study was designed to simulate force feedback sensations under varying conditions of mass and gravity. The software uses a special force feedback mouse, shown in Appendix A. This force feedback can be turned on and off. Figure 5 shows the appearance of the simulation at rest under the varying mass and gravity conditions for the four experiments that were conducted by the participants. The line represents the paddle and the shaded circle represents the ball. Some of the effects of the mass and gravity settings can be seen by the position and appearance of these elements while at rest; others are only apparent while in motion. From the evidence provided by the changing positions and behavior of the software elements, participants drew conclusions about the effects of mass and gravity. With force feedback, effects such as changes in weight can be felt as well as seen.

The main research questions examined whether work with the software had an effect on student reasoning, and whether force feedback impacted student reasoning about the key concepts. Subordinate questions examined whether force feedback was more effective or motivating for various subgroups.

Summary of the Findings

Participants who were able provided brief definitions of key concepts on the pretest. During their work with the simulation, participants noted aspects of the key concepts that they had not conveyed in the pretest, such as changes in the weight or speed of the ball. During the post-experiment interview, students with prior knowledge tended to articulate definitions of key concepts similar to those that they had given in the pretest. When prompted, students could discuss the key concepts in terms of the experiments. Students' had gained knowledge, but it seemed compartmentalized; it was not well integrated with their prior knowledge.

Participants who used the simulation with force feedback tended to score higher on the posttest. The higher score was largely due to a significantly higher score on one of the questions. Question Three queried about the effects of increased gravity. The force feedback effect of weight under maximum gravity is arguably the most powerful example of force feedback among all of the experiments, and thus the scores for this item resulted in the greatest difference between the groups ($t = 2.689$, df=32, p=.011, two-tailed).

The effectiveness of force feedback was not shown to vary with regard to learner attributes such as modal learning preference or gender. There were differences among learning styles; those who had a visual or combined visual-auditory preferred style scored significantly higher than those who did not .

Participants found the experience fun and engaging; this was true regardless of the treatment group. The participants who used force feedback expressed a high degree of interest and enthusiasm for the novel technology and the force feedback effects.

Effects of the Simulation on Student Reasoning

The question of whether working with the simulation had any effect on participants' reasoning about the key concepts was examined by comparing their pretest responses with their comments and their posttest answers. Students' comments during the course of the session also served to illuminate their reasoning processes and developing understanding.

A: Well I learned what mass is, and what happens when you change mass and gravity. And I found out that if balls are in 100, it's very heavy and it's complicated to get it up really high. It's almost impossible to get it up high.

J: Well, I kind of had to think about it, cause in one of my "Calvin and Hobbes" books, Calvin was pretending that he was immune to gravity and he started floating up, so I had to think what, how that happened.

Compartmentalization, Generalization, and Prior Knowledge

In most cases the new experience gained from work with the simulation was not connected or integrated with participants' prior knowledge. This is not surprising, given that the treatment was a brief, one-time event. Students who defined a term in a certain way on the pretest tended to answer the same way on the interview portion, often verbatim, even though in most cases they had given more complex and richer explanations during the course of the experiments. If prompted to think back to the experiments they had done, the majority were able to elaborate on their responses. For instance, when asked to define mass or gravity, many students went back to their original definition as given on the pretest. In the case of gravity, a typical response was that gravity is a force that keeps us on the ground or keeps us from floating. Yet when they were asked to "make the ball heavier," their definition often changed, since most students realized at some point that when they increased the gravity variable the ball became heavier. The simulation experience helped their reasoning about a simulation-related situation, but did not tend to affect their general understanding or definition of the concept, which remained specific and compartmentalized. Still other students had not studied the concepts previously, and so were not affected by prior knowledge because they had none.

Prior knowledge proved helpful on the posttest. Students from School 2, who had prior knowledge of key concepts and were studying mass scored significantly higher than students at School 1, who had no prior knowledge of mass. School 2 also has a dedicated resource teacher and science lab, and these students are accustomed to conducting experiments. The processes of scientific investigation are part of their prior knowledge base, along with their knowledge of the content.

The difficulty with generalization was most evident during interactions with students during the Rules portion of the session. The majority of students struggled with the questions that asked them to generalize rules to describe how the simulation worked; all but a few needed support to reason through the process. Again, this is not surprising given the brief, one-time exposure to the treatment. The following example shows one student's struggle to make a rule about the number of times the ball bounces.

A: So, what I would say about the first question, about how to make a rule that fit in the number of bounces, I would say that it depends on the mass and the gravity temperatures.

LB: Okay, and in what way?

A: Like if you just did, like if you did five and five, then it would be more bounces on the top, and then if you did experiment four, five and 100, and then you wouldn't have very many and experiment three you wouldn't really, it would really be like experiment one. And then experiment two, you get a lot more because it goes slower. So I would say it depends on the mass and the gravity.

LB: Okay so how would you write that so that I would know?

A: It would depend on how you put the mass and the gravity, and how fast the ball goes. That's what I would say.

LB: Okay, but how would you - so if I want to bounce a lot, how would you set the mass and the gravity to make it bounce a lot?

A: Well if you want it to bounce a lot, then I would put it on experiment two, and then really try and hit it.

LB: Okay so experiment two, it bounced the most times?

A: Yeah so if you want it to bounce a lot you would do experiment two. (Inaudible) depends on mass and gravity degrees.

At this point, the student could be prompted to notice what the settings were for mass and gravity, then to notice which experiment did not bounce very much and how those mass and gravity settings were different, then to draw conclusions about the relationships of mass and gravity to bounces. Given individual differences in cognitive development, students varied widely with regard to their ability to do this kind of reasoning and how much support they needed to draw a conclusion about the effects of mass and gravity. In Piagetian terms, most were probably in the concrete operational stage, while a few were in the formal operational stage (Voyat, 1982).

Likewise, some benefited from prompting that helped them to recall prior knowledge and relate it to current experience. In the next example, a boy had stated that gravity had nothing to do with weight.

LB: So what does weight have to do with all of this, do you think? How is weight related? What is weight?

J: How much a person weighs. I don't know how to explain that cause gravity can work on anything, like even a really fat person, but I don't how it can be viewed, be related to weight really.

LB: So would a person always weigh...like if you, if a person is in different gravity, would they weigh the same?

J: Oh, yeah, yeah!! Like if someone weighed a 100 pounds on Earth and then like, if they went to, I don't know, Pluto, they would weigh like 5 pounds.

This example shows that participants may have had some understanding of the concepts, and sometimes more than they realized, but the knowledge is not connected in a coherent fashion. They had perhaps memorized definitions, facts and other prior knowledge, and they had just completed some activities, but they had not integrated the new with the old.

Sometimes students' prior knowledge, often incomplete (e.g., mass is weight), sometimes inaccurate (e.g., heavy things fall faster), became a barrier to or tinged their interpretation of what they were seeing and doing. For instance, one student understood mass to be "an object or thing that takes up space." When discussing the changing weight of the ball, she said, "Yeah, maybe it was bigger but I didn't see it was bigger, but maybe that's just an illusion." Her eyes did not register an increase in size, but her mind told her it must be bigger. Her prior knowledge affected her interpretation of what she saw.

The Concept of Speed

Participants' reasoning about the concept of speed proved to be complex and ever changing. Different students interpreted the word differently, and it also meant different things at different times to the same student. Sometimes speed meant time elapsed: in high gravity experiments, the whole experiment concluded in a few seconds, while in low gravity an experiment could take minutes. Other times, it meant the perceived speed of the ball as determined visually and perhaps haptically. This led students to sometimes give seemingly contradictory responses, even contradicting themselves from one moment to the next. It became apparent that students perceived the acceleration of the ball; its speed was continually changing. The varying amounts of force with which the ball was struck and the elastic force of the paddle further complicated judgments speed and the factors that affected it.

Ten students (8 of 17 in the FF group and 2 of 17 in the No FF group) stated during the interview that experiment 4 was the fastest, even faster than experiment 3, though they both have the same gravitational force. This may have been because the effect of maximum mass and gravity settings causes the paddle to hang very low, and the overall impression is one of stretching and bouncing on the paddle rather than movement through the "air." Once the ball hangs on the paddle, the speed really *is* slower, though when falling, the rate of acceleration is the same. The difference between the FF and No FF groups may have been due partly to the haptic sensation of the elastic force emphasizing the longer contact with the paddle. When the ball strikes the paddle in experiment 4, the rebound is instantaneous, like a ping-pong ball or plastic ball, as some participants described it, so the perceived speed is almost always quick.

Another way to understand speed is by elapsed time. Seventeen participants noted that it took a long time for the ball to come back when it was hit, most often with regard to experiment 1. In the following example, this participant notes both that the ball is taking a long time to return and that it is moving "pretty fast."

H: Slow. I've been waiting for ten minutes for this (inaudible).

LB: Okay so you hit it, what, did you hit it pretty good, you think?

H: Yeah.

LB: And it's taking a long time to come back?

H: Uh-huh.

LB: Okay.

H: Mm-hmm. Pretty fast.

LB: So it's moving pretty fast but is it moving.

H: It's not coming down [...]

Another common occurrence was for a participant to first say the ball was moving slowly and then to say it was moving fast on the same experiment. When asked whether it traveled the same speed in both directions, often the answer was that it went faster in one direction than the other. The ball was sometimes perceived as moving more slowly going up and faster coming down in experiments two, three, and four. These three experiments required more force than the first experiment because of increased mass, gravity, or both, and so students had to work harder to achieve the same upward velocity.

On experiments three and four the maximum gravity setting caused the ball to fall very quickly. It is not clear why the ball in experiment two was sometimes perceived to fall more quickly. The idea that more massive objects fall faster is a common misconception that may have contributed to this perception. For some, the mass of the ball distorting the paddle may have made it seem faster. All of this serves to explain why the simple question, "speed of ball," was not so simple after all.

Effects of Force Feedback

Attitudes and Attention

The addition of force feedback to the visual feedback provided by the simulation appeared to affect student outcomes in a variety of ways. One was due to the novelty of force feedback. None of the participants had used a similar mouse previously, and they were focused on the device for its own sake. Of those who had experienced force feedback before, most experienced it with game controllers that have a "rumble" feature, a less refined form of tactile feedback. Participants found it intriguing to be able to feel changes in the simulation as a result of changing variables.

E: Well I thought it was kind of fun to see like what would happen if you like changed the gravity and mass. And I think it was fun because I got to see, it was and I really liked it. Cool.

E: Like how much force really would be on something if you changed the gravity and mass.

LB: uh-huh.

E: Usually we don't have like more gravity or less mass.

LB: Yeah, it's hard to do that in real life, isn't it?

E: Yeah. It kind of shows you how it feels if you had so much gravity on you.

Participant's attention seemed caught to varying degrees by the haptic feedback, and this provided additional information, but it also meant that less of their attention was on the visual feedback. A certain amount of mental and physical attention is required to monitor the position and action of the mouse with force feedback. That is not to say that it required a large effort, but it factored into the level of student fatigue over the course of the session. With force feedback, the participant's hand must control the mouse at all times. Without it, participants could take a break and just watch the ball bounce.

Force Feedback and Reasoning

Force feedback may have helped participants grasp certain concepts. For instance, a small number of students (3 of 17 in the No FF group, 1 of 17 in the FF group,) thought that the mass control had to do with changes in the mass or elasticity of the paddle, with the one participant in the FF group uncertain of whether it had to do with either the weight of the ball or the paddle. It may be that the force sensation of the ball striking the paddle caused the experimental group to focus more on the changing mass of the ball and results of those changes such as increased weight. With visual feedback only, these few participants concluded that the mass setting controlled attributes of the paddle, with increased mass causing it to become more flexible. In an example from the previous chapter, a participant from the No FF group reasoned that the weight of the ball was unchanging, but that the mass of the paddle "gets stiffer and holds the heavy ball." If she had been able to feel changes in weight, it is likely that she would have concluded that the weight of the ball did in fact change. On the posttest, almost twice as many in the FF group agreed that increasing gravity makes the ball heavier (13 of 17 in the FF group, compared with 7 of 17 in the No FF group).

More in the No FF group (8) agreed with the posttest item that increasing mass makes the ball harder to move compared with 4 in the FF group. This is of interest because it was expected that force feedback would make it more obvious that the ball was harder to move. During the experiments, 12 in the FF group and 8 in the No FF group described the ball as harder to move. The majority of these were in reference to the higher gravity experiments, but 4 in the FF group and 2 in the No FF group described Experiment 2 (high mass, low gravity) as harder to move. It was thought that the ability to feel changes in mass would make the effect of inertia more obvious. That did not happen consistently in this case, though some FF group participants did comment about feeling a "budge" or hesitation with increased mass. The way that the participants struck the ball may have helped some to feel the effect more than others. For instance, the force feedback effect of inertia is more obvious when the user pushes the paddle forward to meet the ball than it is when the paddle is held stationary. As this is an exploratory case study and these are small numbers, it would be worth investigating further.

Modal Learning Preferences and Force Feedback

One of the questions being investigated was whether force feedback was more effective for students who preferred certain modes of learning, whether visual, auditory, or haptic. It was not possible to investigate statistically whether haptic feedback benefited those with a haptic preference because there was only one haptic participant in the group. However in interacting with him, his attention seemed more focused on the force feedback and less on the visual feedback than most students. It appeared that haptic feedback could potentially have a negative effect if it caused him to neglect essential visual feedback.

The proportion of visual learners was greater than expected, based on prior research studies that showed children usually have a more varied preference profile (e.g., (Lemire, 1996). There were 21 participants with a visual preference. Perhaps children are developing a visual preference earlier due to an increased amount of time spent in highly visual pursuits such as television viewing and video game play. Those with a visual preference performed somewhat better than those with an auditory preference, even considering their performance on the interview. The interview portion would seem to possibly favor those with an auditory preference, but because the simulation was primarily visual or visual with force feedback, the participants needed to make sense of information gained through these sensory channels before they could communicate their ideas. Since the essential information was visual, and if those with a preferred visual mode of learning tend to have more skill in visual reasoning, those with a visual learning preference may have had an advantage. Of course, visual preference does not necessarily go hand in hand with strong visual reasoning skills, but it is likely that there is overlap between preference and skill because people often prefer to use their more developed skills to their weaker ones. Students with a mixed visual and auditory preference did as well as or better than the average visual preferring participants on both the interview and posttest portions. During their sessions, two of these seemed particularly adept at "reading" visual information and then articulating their processes of reasoning.

In comparing the posttest total scores of the visual and visual-auditory preferring students with those of the other students, the visual and visual-auditory preferring students performed significantly better ($t= 2.253$, $df=32$, $p=.031$, two-tailed).

It was thought that perhaps force feedback would be more effective for some students, depending on their modal preference. There is some evidence for this, but not in the way that was anticipated. Visual learners, rather than being distracted in a negative way from their preferred mode of learning, appeared to benefit from the added feedback. In analyzing the posttest scores of those participants with a visual preference, the FF group performed marginally better than the No FF group. From these results, it does not appear that haptic feedback was detrimental to the learning of those participants who expressed a visual preference. Instead, it seemed that might have added information without detracting excessively from their generally strong visual reasoning skills. In the case of the haptic learner, observational data raised the question of a possibly negative effect if the added stimulation distracted him from essential visual information. However, no preference groups or subgroups were shown to have had a negative outcome from interaction with force feedback; all groups performed significantly or marginally better.

Prior Game Experience

In examining the frequency of computer and video game play, a clear relationship between frequency of game play or force feedback game play and performance was not found. However, those participants who play games with force feedback on a daily basis had slightly lower than average scores on the posttest. Perhaps the kinds of games being played were a factor here; games with force feedback are usually played on game consoles or at an arcade, and typically would not be considered educational or edutainment games. It could also be that the amount of time devoted to game play was displacing other activities such as homework. This is speculation; participants were not questioned about the amount of time spent or kind of games played, only about their frequency of game play.

While there was no statistically significant evidence for an effect from game play, there was anecdotal evidence from two boys who did better than average and who commented individually on their personal interests. The first boy asked about the development of the software. He then said that he wanted to learn to be a 3D animator because he wanted to make graphics for video games some day.

The second boy said that he loved computer games and played them almost every day. His favorite game was *Minesweeper*, the ubiquitous Microsoft® game. Even though it is not an educational game per se, the game does require logic and visual reasoning skills. He was proud that he had conquered the game in "expert" mode over the course of two days. He went on further to describe a computer game that he played with his father. Though it was ostensibly a baseball game, players could only score a homerun by answering a math problem correctly. It may be that their experience with the simulation meshed well with these students' interests and skills, and their prior interests helped to prepare them for their participation.

Instructional Design Issues

The software that was used in this study was not designed for educational purposes. It was designed as a demonstration program to showcase the capabilities of the force feedback technology. Because of this, the software is simple, and certain features that would be helpful from an instructional standpoint were not included. For instance, the identical mass and gravity slider controls, while simple to use, may have added to participants' confusion about the relationship between mass and gravity. Numeric displays of information such as the rate of acceleration and the mass of the ball would better convey the meaning of the mass and gravity variables and help children understand that they are not measured with similar units.

Another confusing aspect of the software for a few students was where the ball went when it left the screen. The majority of students who expressed an opinion reasoned that the ball traveled far when it was gone for a long time, but some still wanted to know where it went. One girl wished specifically for a version of the software with a bigger screen. Given the distance that the ball travels with low mass and gravity this is probably impossible to accomplish, but a numeric display could serve to convey the distance traveled.

Aside from these shortcomings, the software provides an effective demonstration of paddleball under extreme and varying conditions of mass and gravity. A great benefit of force feedback is that it can simulate the effects of gravitational force and allow students to manipulate objects under varying conditions, something that is prohibitively difficult and expensive to do in real life. The software could be used as-is for various purposes, such as a class demonstration and discussion of multiple forces acting on an object, perhaps for eighth grade students.

Conceptual Development

Some findings from the study did not relate directly to effects of the technology, but to participants' reasoning processes and beliefs. One finding was that students who had expressed almost identical definitions of gravity, when questioned further, had widely divergent mental models, with half of these believing that gravity is a force in the atmosphere that pushes down. The prevalence of this belief was more surprising than the divergence. The extent of this belief was not readily apparent from the pretest and initial questioning; it only became apparent when one of the students said something intriguing that caused further questioning. It is likely that many of the students who were not questioned further held similar beliefs or other beliefs that would affect the way that they interpreted and assimilated related information.

Another finding was that about two-thirds of the students used metaphor in discussing the experiments and concepts. While it is often useful to relate new information to known models, it can also create problems if carried to extreme. For instance, some of the participants described the action of the ball and paddle as if they had volition. This was acceptable for descriptive purposes, but could create problems if taken literally. Educators can help to address both of these issues through awareness, questioning and discussion.

Suggestions for Using Haptic Feedback

The following suggestions may be helpful to researchers, educators or instructional designers who are interested in researching or using haptic feedback in learning situations.

Instructional Design

Haptic feedback is probably best used where it can promote an understanding of the content. While force feedback was not shown to be detrimental to visual reasoning, it does draw the learner's attention. It may be helpful to use it to reinforce concepts with instruction, but consider turning off force feedback initially when the new information being presented is primarily visual (e.g., to focus attention on numeric displays within a simulation). It is advantageous that force feedback can be turned off and on. Previous studies have found it also can be used effectively to aid in the performance of tasks where accuracy and speed are important factors, since it reduces the need for reliance on visual perception.

User testing is an essential component of instructional software design, but it is even more important with a new and relatively untried technology for which best practices have not been developed. Designs that look promising on paper can have unintended side effects, and the only way to uncover these is through testing.

Science Education

Students without strong visual reasoning skills may be at a disadvantage when working with simulation software. Though force feedback was shown to be at least marginally helpful for the study participants regardless of learning preference, those with weaker visual reasoning skills should be encouraged to develop those skills. It is advisable to turn off the force feedback to focus learner attention on visual feedback when necessary, particularly for those learners who find it difficult to focus on visual information.

It is also important to assess the state of learners' knowledge and beliefs prior to experimentation. This not only affected the participants' ability to understand and build on their content knowledge; it was also shown to affect how participants interpreted the results of their experiments through visual and haptic feedback.

Limitations of the Study

The treatment was designed as a series of structured but open-ended experiments to organize students' experience with the simulation. In other words, it was not designed to teach the concepts, but to investigate how the children learned and reasoned by working through the activities with the software, as the central purpose of this project was to study the effect of the technology on students' reasoning. This design was intended as a middle ground between offering a completely open-ended, but potentially chaotic environment for experimentation and offering a structured instructional unit. This approach had an impact on the outcome of the study; the effect of the technology cannot be separated entirely from the effect of the supporting materials and the structure of the study. For instance, the order of the experiments probably had an effect on the way participants described the relative speed of the experiments, since they were comparing subsequent experiments to the previous one.

The simulation software that was used in this study was not designed as a learning tool. Because of this, participants were required to make judgments mostly based on their sensory impressions rather than on measurements. On the one hand, this was a useful way to see the effects of the visual and haptic senses on participants' reasoning and the effect of their thought processes on their interpretations of what they were seeing and feeling. But the software's effectiveness as a learning tool could have been enhanced if, for example, the software displayed the rate of acceleration, velocity, distance traveled, and elapsed time. One way that the software probably misled participants was in its use of identical scales for mass and gravity. Students tended to discuss mass and gravity as balancing each other or as being in equal or unequal amounts, and the control panel scale probably promoted this line of reasoning.

The intervention was very brief considering the number and complexity of the concepts in question. Contrast this with the fact that the students at one of the schools had spent several weeks on just one of the concepts.

Although this was a short-term study, the individual sessions could be somewhat long and therefore tiring. Ideally, students would have been able to use the simulation over a number of sessions to build on their understanding. Recent research has shown that learning is maximized when people have a chance to process recently learned knowledge during sleep (Bower, 2004; Cromie, 2003). Participants may have been better able to integrate their experiences and connect them to their prior knowledge if their participation took place over time. Another benefit would have been that discussions could have continued; sometimes conversations were cut short due to time constraints and participant fatigue.

Another limitation of the study was that it took place over several weeks; this could have had some impact on student performance, particularly among those students who were concurrently studying mass. In discussing this with their science teacher, no obvious instances of time-sensitive improved performance could be pinpointed, but the effect could exist nonetheless.

Because this was an exploratory case study and given the time constraints of the individual sessions, the posttest was very brief. As a result, it is likely that it was not powerful enough to pick up differences that existed. Also, it did not include several of the concepts that the participants described during their experimentation, just those that were deemed most important. It would be useful to have more concepts included in the posttest to compare students' understanding of the concepts that were discussed.

Another potential issue with the posttest was its unusual design. Participants were to select as many answers as were correct for each question. This design made the scoring and evaluation process less obvious and straightforward. The design did not seem to confuse the participants, and children this age do this sort of activity regularly, but it is unusual for testing purposes. Single answer multiple-choice questions are more common. On the other hand, it may have been easier than a comparable true-false quiz, because the items were grouped by question (topic) rather than randomly mixed. This provided an organized structure for considering the concepts.

The distribution of the visual and visual-auditory participants between the control and experimental group may have inadvertently statistically advantaged the control group slightly. In an effort to distribute at least one of each learning style in the experimental group and other constraints, more of the visual-auditory students were placed in the control group. The total number of visual and visual-auditory students in the control group was 14, compared with 12 in the experimental group.

Further Research

In exploring the question of how force feedback impacts student reasoning, this study followed a middle ground between unconstrained exploration and a fixed lesson in the subject matter. Because of this students of varying abilities could participate and derive benefit from their participation. The detriment of this approach is that the question of the effect of force feedback is somewhat compromised, since the structure of the experiments also affected outcomes. The benefit is that the student could be guided in a direction that would provide a coherent experience in an abbreviated time frame.

Another approach to a similar problem would be to devise a case study that focused more on the content. The study could follow a complete instructional unit; this would be of interest to see whether students who practiced with the simulation and force feedback benefited more than those who did not. One way to implement a longer-term intervention (over weeks) would be to have students practice on their own. They could keep a written record of their activities and answer journal prompts as evidence of their participation.

A more ambitious and expensive study could be done by first developing a new version of the software. The new software could be enhanced with features that would make it easier for students to compare and contrast experiments, and measure distance, rate of acceleration, and velocity, though this would also shift the focus away from sensory reasoning.

Although participants as a whole generally performed slightly better with force feedback than without, those who professed a visual or visual-auditory preference performed significantly better than the others. It may be that they preferred the visual mode because they have strong visual reasoning skills. A similar study that grouped participants by visual reasoning skills rather than modal preference could investigate this.

Because this was an exploratory study, the focus was wide. This limited the depth of research into any particular aspect of the study, but offered glimpses into several intriguing aspects of students' reasoning that could be explored further in more narrowly-focused studies. For instance, a focus on the development on one or two of the concepts such as speed or gravity and weight could provide fertile ground for investigation.

The current study is only a starting point for research into the effects of haptic feedback on children's cognition. But it suggests several potentially fruitful directions for research that could further knowledge in this relatively unexplored area.

References

American Association for the Advancement of Science. (1989). *Science for all americans*. New York: Oxford.

Anderson, J. R. (2000). *Cognitive psychology and its implications* (Fifth ed.). New York: Worth Publishers.

Beichner, R. J. (1995). Considering perception and cognition in the design of an instructional software package. *Multimedia Tools and Applications, 1*, 173-184.

Blackwell, P. L. (2000). The influence of touch on child development: Implications for intervention. *Infants and Young Children, 13*(1), 25-39.

Bower, B. (2004, January 4). *Sleeper effects: Slumber may fortify memory, stir insight.* Retrieved March 10, 2004, from http://www.sciencenews.org/articles/20040124/fob5.asp

Burdea, G. (1996). *Force and touch feedback for virtual reality.* New York: John Wiley & Sons, Inc.

California Department of Education. *(1998) Science content standards of california public schools: Kindergarten through grade twelve.* (1998). Sacramento, CA: California Department of Education.

Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five traditions*. Thousand Oaks, CA: Sage Publications.

Cromie, W. J. (2003). *New stage of memory found.* Retrieved March 10, 2004, from http://www.news.harvard.edu/gazette/2003/11.20/01-sleep.html

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. New York: Harper & Row, Publishers, Inc.

California Department of Education. *DataQuest.* Retrieved February 25, 2004, from http://data1.cde.ca.gov/dataquest/

Deaton, W. L. (1992). Review of the learning channel preference checklist. In J. J. Kramer & J. C. Conoley (Eds.), *The eleventh mental measurements yearbook* (pp. 454-455). Lincoln, NE: University of Nebraska Press.

Dekkers, P. J. J. M., & Thijs, G. D. (1998). Making productive use of students' initial conceptions in developing the concept of force. *Science Education, 82*(1), 31-51.

Gibson, J. J. (1982). *Reasons for realism: Selected essays of james j. Gibson.* Hillsdale: NJ: Lawrence Erlbaum Associates, Inc. Publishers.

Gredler, M. E. (1996). Educational games and simulations: A technology in search of a (research) paradigm. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology.* New York: Macmillan Library Reference USA.

Greene, B. D., Herman, M., & Haury, D. L. (2000). *Timss: What have we learned about math and science teaching? Eric digest.* (No. EDO-SE-00-05). Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education.

Hart, C. (2002). If the sun burns you is that a force? Some definitional prerequisites for understanding newton's laws. *Physics Education, 37*(3), 234-238.

Hasser, C. J., & Massie, T. H. (1996). The haptic illusion. In C. Dodsworth (Ed.), *Digital illusion: Entertaining the future with high technology*: Addison-Wesley Publ. Co.

Hughes, J. N. (1992). Review of the learning style inventory. In J. J. Kramer & J. C. Conoley (Eds.), *The eleventh mental measurements yearbook* (pp. 460-461). Lincoln, NE: University of Nebraska Press.

Hynd, C. R., McNish, M. M., Qian, G., Keith, M., & Lay, K. *Learning counterintuitive physics concepts:The effects of text and educational environment.* Retrieved December 22, 2001, from http://curry.edschool.virginia.edu/go/clic/nrrc/phys_r16.html

Johnson, M. (1987). *The body in the mind: The bodily basis of meaning, imagination, and reason.* Chicago: The University of Chicago Press.

Knapp, T. R. (1998). Review of the learning style inventory. In J. C. Impara & B. S. Plake (Eds.), *The thirteenth mental measurements yearbook* (pp. 608-609). Lincoln, NE: University of Nebraska Press.

Kroonenberg, N. (1995). Meeting language learner's sensory-learning style preferences. In J. M. Reid (Ed.), *Learning styles in the esl/efl classroom.* New York: Heinle & Heinle Publishers.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by.* Chicago: The University of Chicago Press.

Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh.* New York: Basic Books.

Lakoff, G., & Nuñez, R. E. (2000). *Where mathematics comes from: How the embodied mind brings mathematics into being.* New York: Basic Books.

Landry, C. E., & Forman, G. E. (1999). Research on early science education. In C. Seefeldt (Ed.), *The early childhood curriculum: Current findings in theory and practice* (pp. 133-158). New York: Teachers College Press.

Lemire, D. (1996). Using learning styles in education: Research and problems. *Journal of accelerated learning and teaching, 21*(1 and 2), 45-59.

Mathewson, J. H. (1999). Visual-spatial thinking: An aspect of science overlooked by educators. *Science Education, 83*(1), 33-54.

Mayer, R. E. (2001). *Multimedia learning*. Cambridge: Cambridge University Press.

McCloskey, M., Caramazza, A., & Green, B. (1980). Curvilinear motion in the absence of external forces: Naive beliefs about the motion of objects. *Science, 210*(5 December 1980), 1139-1141.

Monaghan, J. M., & Clement, J. (1995). *Use of collaborative computer simulation activities to facilitate relative motion learning*. Retrieved November 12, 2001, from http://www-cscl95.indiana.edu/cscl95/monaghan.html

Monaghan, J. M., & Clement, J. (1999). Use of a computer simulation to develop mental simulations for understanding relative motion concepts. *International Journal of Science Education, 21*(9), 921-944.

Mullis, I. V. S., Martin, M. O., Fierros, E. G., Goldberg, A. L., & Stemler, S. E. (2000). *Gender differences in achievement: IEA's third international mathematics and science study (TIMSS)*. Chestnut Hill, MA: International Study Center, Lynch School of Education, Boston College.

Neisser, U. (1976). *Cognition and reality: Principles and implications of cognitive psychology*. New York: W. H. Freeman and Company.

Norman, D. A. (1988). *The psychology of everyday things*. New York: Basic Books, Inc.

Oakley, I., McGee, M. R., Brewster, S., & Gray, P. (2000). *Putting the feel in 'look and feel'*. Retrieved October 3, 2000, from http://www.dcs.gla.ac.uk/~stephen/papers/CHI2000.pdf

O'Brien, L. (1991). Learning channel preference update. *On the beam: New horizons for learning, XI*(3), 4.

Paivio, A. (1986). *Mental representations: A dual coding approach*. New York: Oxford University Press.

Palmer, D. H. (1999). Exploring the link betweeen students' scientific and nonscientific conceptions. *Science Education, 83*(6).

Palmer, D. H. (2001). Students' alternative conceptions and scientifically acceptable conceptions about gravity. *International Journal of Science Education, 23*(7), 691-706.

Piaget, J. (1970). *The child's conception of physical causality.* London: Routledge & Kegan Paul, LTD.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accomodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227.

Reid, J. M. (1987). The learning style preference of esl students. *TESOL Quarterly, 21*(1), 87-111.

Reiner, M. (1999). Conceptual construction of fields through tactile interface. *Interactive Learning Environments, 7*(1), 31-55.

Richard, P., Birebent, G., Coiffet, P., Burdea, G., Gomes, D., & Langrana, N. (1996). Effect of frame rate and force feedback on virtual object manipulation. *Presence, 5*(1), 95-108.

Sallnäs, E.-L. (2000). *Supporting collaboration in distributed environments by haptoc force feedback.* Retrieved October 2, 2000, from http://www.dcs.gla.ac.uk/%7Estephen/workshops/haptic/papers/sallnas.pdf

Stevenson, H. W. (1998). *A TIMSS primer: Lessons and implications for U.S. Education.* Retrieved May 7, 2003, from http://www.edexcellence.net/library/timss.html#anchor411627

Thomson, B. S. (1997, June 1997). *Attending to learning styles in mathematics and science classrooms. Eric digest.* Retrieved August 2, 2003, from http://www.ericfacility.net/ericdigests/ed432440.html

Thomson, B. S., & Mascazine, J. R. (2003, June 2003). *Attending to learning styles in mathematics and science classrooms.* Retrieved August 11, 2003, from http://www.ericse.org/digests/dse97-4.html

Van Scoy, F. L., Kawai, T., Darrah, M., & Rash, C. (2000, September 1, 2000). *Haptic display of mathematical functions for teaching mathematics to students with vision disabilities.* Paper presented at the Haptic Human-Computer Interaction Workshop, University of Glasgow.

Viadero, D. (1999). *Setting the record straight.* Retrieved September 11, 2000, from http://www.edweek.org/ew/ewstory.cfm?sl0ug=13misconceptions.h19&keywords=viadero

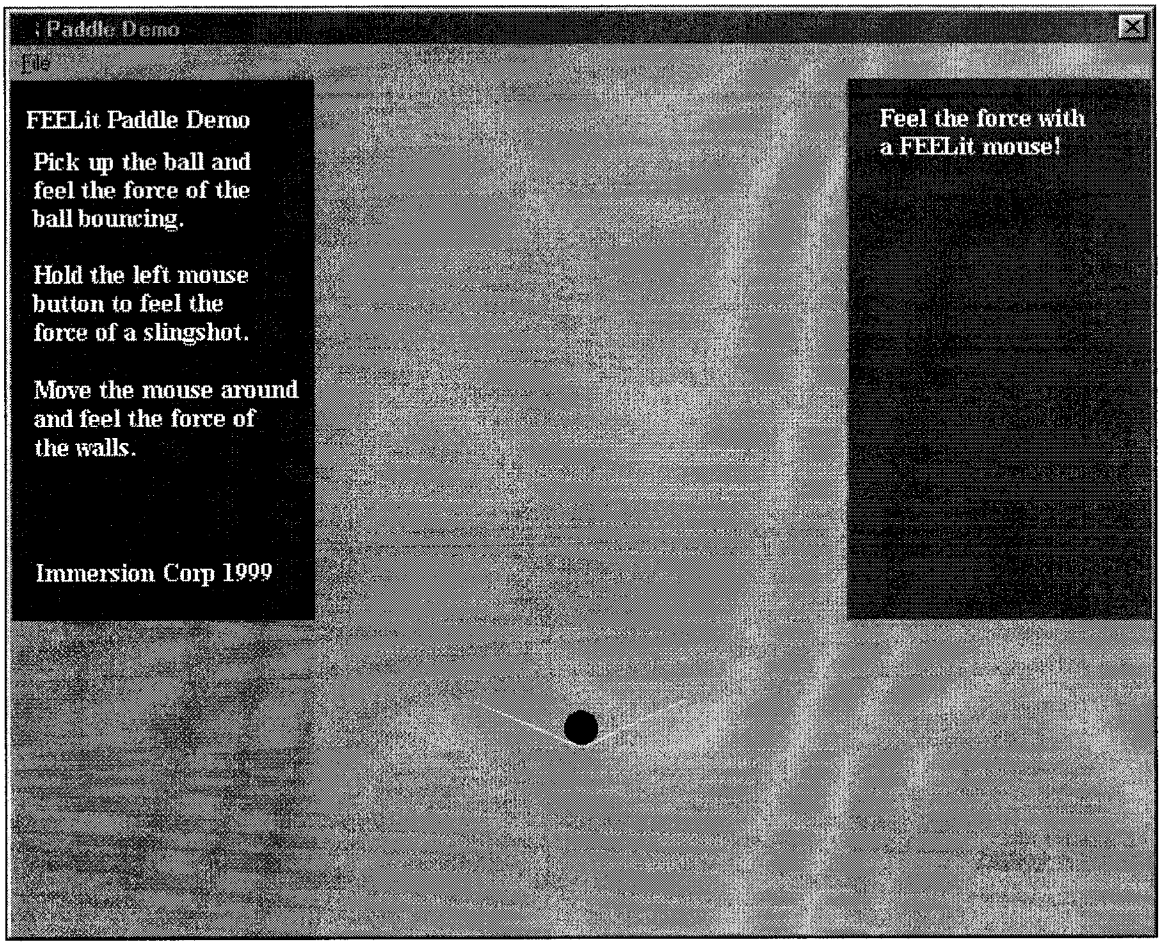
Voyat, G. E. (1982). *Piaget systematized.* Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Wies, E. F., Gardner, J. A., O'Modhrain, M. S., Hasser, C. J., & Bulatov, V. L. (2000). *Web-based touch display for accessible science education.* Retrieved September 18, 2000

Windschitl, M. A. (1995). Using computer simulations to enhance conceptual change: The roles of constructivist instruction and student epistemological beliefs. *Dissertation Abstracts International, 56* (07), 2551. (UMI No. 9540954)

Appendix A: Screen Layout, Control Panel, and Force Feedback Mouse

Software Screen Layout



FEELit Paddle Demo

Pick up the ball and feel the force of the ball bouncing.

Hold the left mouse button to feel the force of a slingshot.

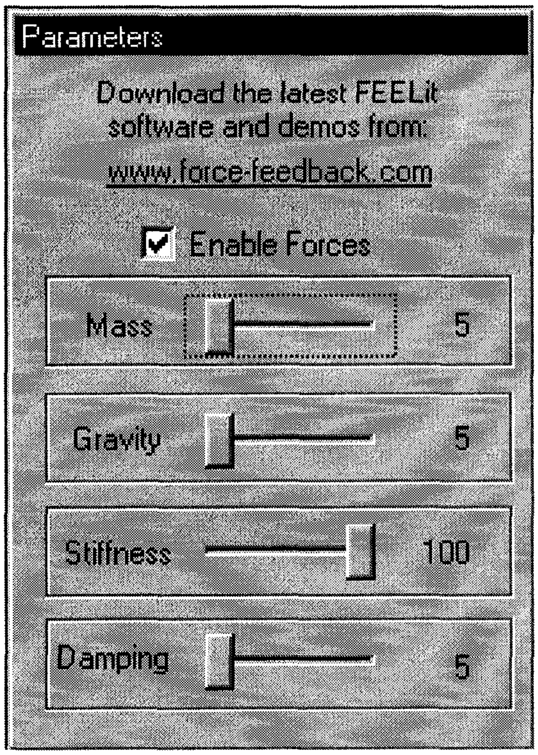
Move the mouse around and feel the force of the walls.

Immersion Corp 1999

Feel the force with a FEELit mouse!

Reproduced by permission of Immersion Corporation.

Software Control Panel



Download the latest FEELit software and demos from:
www.force-feedback.com

☑ Enable Forces

Mass 5

Gravity 5

Stiffness 100

Damping 5

Reproduced by permission of Immersion Corporation.

WingMan Force Feedback Mouse

Logitech® WingMan® Force Feedback Mouse.

Photograph courtesy of Logitech. Used with permission.

Appendix B: Instruments

Pretest

Directions for questions 1–5: Answer as many as you can, the best you can.

1. What is mass?

2. What is force?

3. What is an example of force?

4. What is gravity?

5. I have a computer at home. Yes No

6. I play computer or video games:

Every day or almost every day	At least once a week	Once in a while	Never or almost never

7. I have played computer or video games where I can ***feel*** what is happening in the game (bumps in the road, crashes).

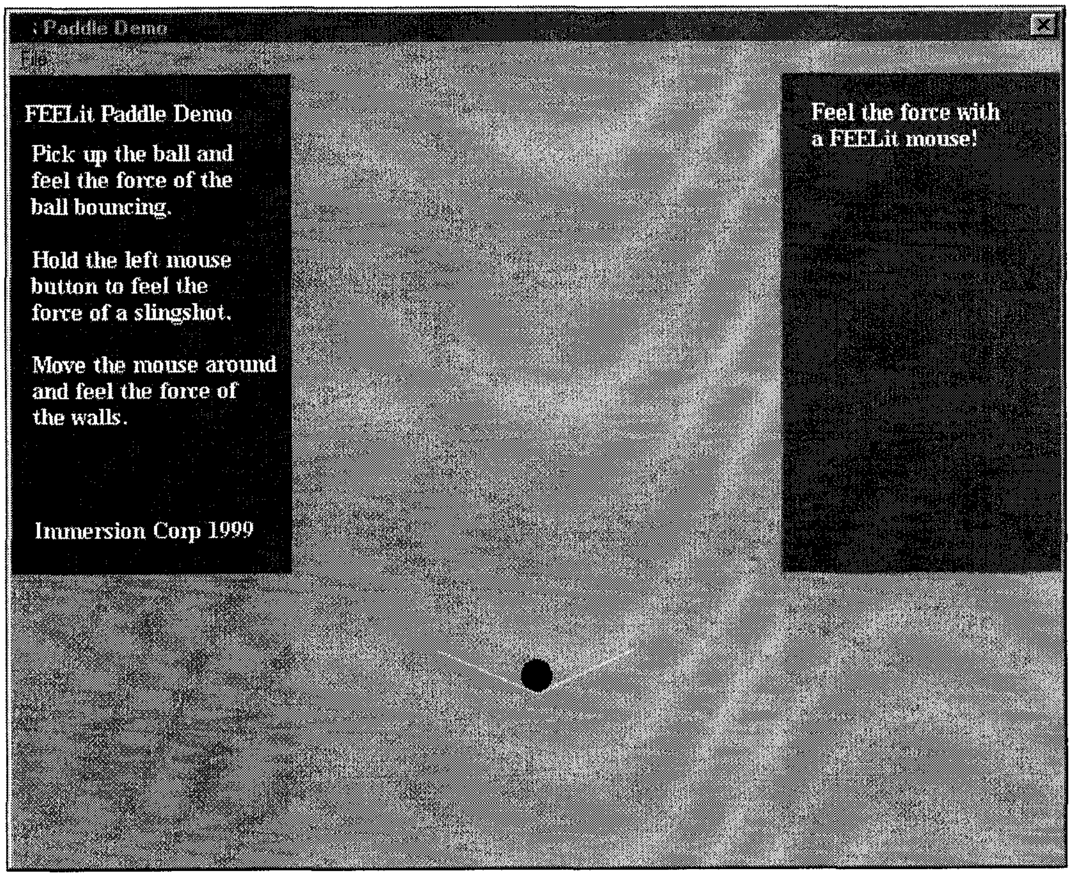
Every day or almost every day	At least once a week	Once in a while	Never or almost never

8. I play at (circle all that apply)

home library Video arcade Other______________________________

Directions

- The ball always returns straight down the middle of the screen. “Bank shots” don’t work.
- If you hold the mouse button down, the ball will stick to the paddle.
- The paddle works better if you keep it away from the bottom. Try to keep it in the part of the window shown below.



FEELit Paddle Demo

Pick up the ball and feel the force of the ball bouncing.

Hold the left mouse button to feel the force of a slingshot.

Move the mouse around and feel the force of the walls.

Immersion Corp 1999

Feel the force with a FEELit mouse!

Go ahead and play with it for a few minutes before we get started...

- Repeat each experiment several times before moving on to the next.
- You can always go back to a previous step if you want to.
- For each step, describe what is happening. Pay attention to changes in:

☐ the ball
☐ the paddle
☐ motion
☐ speed
☐ feel (touch)
☐ the mouse

Experiment Worksheet

1. For each experiment, change the mass and gravity settings to match the settings below. Bounce the ball several times to get the feel of it.
2. Give the ball a good whack and let it bounce until it stops. Keep your hand on the mouse so the paddle does not move.

Stiffness = 100 Damping=5	Experiment 1	Experiment 2
Mass	5	100
Gravity	5	5
Speed of ball?		
How hard did you hit the ball?		
Describe what you see and feel when the ball hits the paddle.		
Number of bounces? (hit ball to top of screen)		
What has changed from the last experiment?		

Stiffness = 100 Damping=5	Experiment 3	Experiment 4
Mass	100	5
Gravity	100	100
Speed of ball?		
How hard did you hit the ball?		
Describe what you see and feel when the ball hits the paddle.		
Number of bounces? (hit ball to top of screen if you can)		
What has changed from the last experiment?		

Look over the data you have collected as you complete the following:

Make a rule that describes the number of times the ball bounces.

Make a rule that describes the speed of the ball.

Make a rule that describes what you see and feel when the ball hits the paddle.

Interview Protocol

1. Review (skim) each of the student's recorded observations and ask for clarification, if necessary.

2. What is mass?

3. What is gravity?

4. What is weight?

5. How can you make the ball as heavy as possible? (Describe.)

6. Have the student bounce the ball with the paddle set on low to medium gravity. Ask: What do you think will happen if we increase the gravity? (Have student try it and observe results. Have student explain results.)

Settings	
Mass	50
Gravity	**5 ->50**
Stiffness	100
Damping	5

7. Have the student bounce the ball with the ball set on low mass. Ask: What do you think will happen if we increase the mass of the ball? (Have student try it and observe results. Have student explain results.)

Settings	
Mass	**20 -> 100**
Gravity	50
Stiffness	100
Damping	5

8. What did you think of this activity? (If s/he just “liked” or “didn’t like” it, elicit more detail)

9. Did you learn anything new? (If so: What? If not: Why not?)

10. Did this help you learn about mass and gravity? (If so: How? If not: Why not?)

11. Imagine you can design a software program that uses this technology to help people learn about something else. What could the software you design help people learn?

Posttest

1. How can you increase the weight of the ball?
    a. Increase the mass of the ball
    b. Increase the gravity
    c. Decrease the stiffness
    d. Decrease the mass of the ball

2. What affects the speed that the ball falls?
    a. The mass of the ball
    b. Gravity
    c. Both the mass of the ball and gravity
    d. None of the above

3. What happens when you increase the gravity?
    a. The mass of the ball increases
    b. The ball becomes heavier
    c. The ball falls faster
    d. The ball falls slower

4. What happens when you increase the mass?
    a. The ball becomes heavier
    b. The ball falls faster
    c. The ball becomes harder to move
    d. The ball falls more slowly

5. What happens when you decrease the gravity?

    a. The ball becomes heavier
    b. The ball becomes lighter
    c. The ball falls faster
    d. The ball falls more slowly

6. What happens when you decrease the mass?

    a. The gravity increases
    b. The ball falls more slowly
    c. The ball becomes lighter
    d. The ball falls more quickly

7. Did you enjoy this activity?

Yes Not sure No

8. Would you like to do an activity like this in school?

Yes Not sure No

9. What topic(s) did you learn about? (circle **all** that apply)

Mass Gravity Weight Force

10. What topic(s) have you studied before? (circle **all** that apply)

Mass Gravity Weight Force

Appendix C: Data Codes

```
QSR N6 Full version, revision 6.0.
Licensee: Linda Bussell.

PROJECT: dissertation, User Linda Bussell, 5:36 pm, Mar 30, 2004.


REPORT ON NODES FROM Tree Nodes '~/Experiment 1'
Depth: ALL
Restriction on coding data: NONE

************************************************************************
(1)                     /Parts of Interview
This node codes 0 documents.
************************************************************************
(1 1)                   /Parts of Interview/Experiment 1
This node codes 34 documents.
************************************************************************
(1 2)                   /Parts of Interview/Experiment 2
This node codes 34 documents.
************************************************************************
(1 3)                   /Parts of Interview/Experiment 3
This node codes 34 documents.
************************************************************************
(1 4)                   /Parts of Interview/Experiment 4
This node codes 34 documents.
************************************************************************
(1 5)                   /Parts of Interview/Rules
This node codes 33 documents.
************************************************************************
(1 6)                   /Parts of Interview/define/describe mass
This node codes 34 documents.
************************************************************************
(1 7)                   /Parts of Interview/define/describe gravity
This node codes 34 documents.
************************************************************************
(1 8)                   /Parts of Interview/define/describe weight
This node codes 33 documents.
************************************************************************
(1 9)                   /Parts of Interview/make heaviest ball
This node codes 34 documents.
************************************************************************
(1 10)                  /Parts of Interview/make prediction 1
This node codes 34 documents.
************************************************************************
(1 11)                  /Parts of Interview/make prediction 2
This node codes 34 documents.
************************************************************************
(1 12)                  /Parts of Interview/attitude re experience
This node codes 34 documents.
************************************************************************
(1 13)                  /Parts of Interview/software design ideas
This node codes 34 documents.
************************************************************************
(1 13 1)                /Parts of Interview/software design ideas/dance
This node codes 1 document.
************************************************************************
(1 13 2)                /Parts of Interview/software design ideas/air
```

```
This node codes 1 document.
************************************************************************
(1 13 3)                /Parts of Interview/software design
ideas/reading, writing
This node codes 3 documents.
************************************************************************
(1 13 3 1)              /Parts of Interview/software design
ideas/reading, writing/spelling
This node codes 1 document.
************************************************************************
(1 13 4)                /Parts of Interview/software design
ideas/computers, internet
This node codes 2 documents.
************************************************************************
(1 13 5)                /Parts of Interview/software design ideas/music
This node codes 2 documents.
************************************************************************
(1 13 6)                /Parts of Interview/software design ideas/art
This node codes 2 documents.
************************************************************************
(1 13 7)                /Parts of Interview/software design ideas/being
a doctor
This node codes 1 document.
************************************************************************
(1 13 8)                /Parts of Interview/software design ideas/math
This node codes 5 documents.
************************************************************************
(1 13 9)                /Parts of Interview/software design ideas/mass &
gravity
This node codes 3 documents.
************************************************************************
(1 13 9 1)              /Parts of Interview/software design ideas/mass &
gravity/define with examples
This node codes 1 document.
************************************************************************
(1 13 9 2)              /Parts of Interview/software design ideas/mass &
gravity/game to test
This node codes 1 document.
************************************************************************
(1 13 9 8)              /Parts of Interview/software design ideas/mass &
gravity/higher mass & gravity
This node codes 1 document.
************************************************************************
(1 13 10)               /Parts of Interview/software design ideas/space
This node codes 2 documents.
************************************************************************
(1 13 11)               /Parts of Interview/software design ideas/bigger
screen
This node codes 1 document.
************************************************************************
(1 13 12)               /Parts of Interview/software design ideas/horses
This node codes 1 document.
************************************************************************
(1 13 13)               /Parts of Interview/software design
ideas/history
This node codes 1 document.
************************************************************************
```

```
(1 13 14)                /Parts of Interview/software design ideas/feel
effects of tools, flight
This node codes 1 document.
*************************************************************************
(1 13 15)                /Parts of Interview/software design ideas/cool
games like this
This node codes 2 documents.
*************************************************************************
(1 13 15 1)              /Parts of Interview/software design ideas/cool
games like this/teeter-totter game
This node codes 1 document.
*************************************************************************
(1 13 16)                /Parts of Interview/software design ideas/feel
forces in sports
This node codes 2 documents.
*************************************************************************
(1 13 17)                /Parts of Interview/software design
ideas/weighing different objects
This node codes 1 document.
*************************************************************************
(1 13 18)                /Parts of Interview/software design
ideas/science
This node codes 1 document.
*************************************************************************
(1 13 18 1)              /Parts of Interview/software design
ideas/science/water cycle
This node codes 1 document.
*************************************************************************
(1 13 18 2)              /Parts of Interview/software design
ideas/science/couldn't teach science
This node codes 1 document.
*************************************************************************
(1 13 19)                /Parts of Interview/software design ideas/Yu-gi-
oh cards
This node codes 1 document.
*************************************************************************
(1 13 20)                /Parts of Interview/software design ideas/feel
objects with VR glove
This node codes 1 document.
*************************************************************************
(1 13 21)                /Parts of Interview/software design
ideas/(friendly) robots, machines
This node codes 1 document.
*************************************************************************
(1 13 22)                /Parts of Interview/software design ideas/have
President give WFFM to everyone
This node codes 1 document.
*************************************************************************
(1 14)                   /Parts of Interview/pretest definitions
This node codes 33 documents.
*************************************************************************
(2)                      /Gravity
This node codes 0 documents.
*************************************************************************
(2 1)                    /Gravity/surrounds us, in the air
This node codes 6 documents.
*************************************************************************
```

```
(2 2)                   /Gravity/holds us, keeps us from falling over
This node codes 3 documents.
************************************************************************
(2 3)                   /Gravity/makes heavier
This node codes 21 documents.
************************************************************************
(2 4)                   /Gravity/makes paddle hang more
This node codes 14 documents.
************************************************************************
(2 5)                   /Gravity/makes bouncier
This node codes 7 documents.
************************************************************************
(2 6)                   /Gravity/pushes down
This node codes 9 documents.
************************************************************************
(2 7)                   /Gravity/makes less bouncy
This node codes 14 documents.
************************************************************************
(2 8)                   /Gravity/more makes slower
This node codes 7 documents.
************************************************************************
(2 9)                   /Gravity/more makes faster
This node codes 24 documents.
************************************************************************
(2 10)                  /Gravity/makes ball go higher
This node codes 6 documents.
************************************************************************
(2 11)                  /Gravity/makes us float
This node codes 5 documents.
************************************************************************
(2 11 1)                /Gravity/makes us float/if there's no air
This node codes 1 document.
************************************************************************
(2 12)                  /Gravity/keeps us down, makes things fall
This node codes 25 documents.
************************************************************************
(2 13)                  /Gravity/makes paddle hang less
This node codes 1 document.
************************************************************************
(2 14)                  /Gravity/protects us
This node codes 1 document.
************************************************************************
(2 15)                  /Gravity/in the ground
This node codes 6 documents.
************************************************************************
(2 16)                  /Gravity/ball stays on the paddle
This node codes 5 documents.
************************************************************************
(2 17)                  /Gravity/changes in gravity change mass
This node codes 2 documents.
************************************************************************
(2 18)                  /Gravity/gravity is in space
This node codes 2 documents.
************************************************************************
(2 19)                  /Gravity/force coming down, pulling
This node codes 14 documents.
************************************************************************
```

```
(2 20)                  /Gravity/pull of object on another object
This node codes 5 documents.
************************************************************************
(2 21)                  /Gravity/pulling toward Earth's core
This node codes 1 document.
************************************************************************
(2 22)                  /Gravity/centrifugal force
This node codes 1 document.
************************************************************************
(2 23)                  /Gravity/controls planetary motion
This node codes 1 document.
************************************************************************
(2 24)                  /Gravity/has mass
This node codes 1 document.
************************************************************************
(2 25)                  /Gravity/pushes up
This node codes 1 document.
************************************************************************
(2 26)                  /Gravity/changes speed
This node codes 1 document.
************************************************************************
(2 29)                  /Gravity/high gravity- ball doesn't go far
This node codes 1 document.
************************************************************************
(2 31)                  /Gravity/is in the ball
This node codes 1 document.
************************************************************************
(2 34)                  /Gravity/does NOT control bounces
This node codes 1 document.
************************************************************************
(3)                     /Mass
This node codes 0 documents.
************************************************************************
(3 1)                   /Mass/takes up space
This node codes 10 documents.
************************************************************************
(3 2)                   /Mass/makes ball go farther
This node codes 9 documents.
************************************************************************
(3 3)                   /Mass/refers to the paddle
This node codes 4 documents.
************************************************************************
(3 4)                   /Mass/doesn't do much
This node codes 1 document.
************************************************************************
(3 5)                   /Mass/makes bouncier
This node codes 25 documents.
************************************************************************
(3 6)                   /Mass/makes heavier
This node codes 26 documents.
************************************************************************
(3 7)                   /Mass/same as gravity
This node codes 4 documents.
************************************************************************
(3 8)                   /Mass/how much force is in object
This node codes 2 documents.
************************************************************************
```

```
(3 9)                   /Mass/studied mass
This node codes 10 documents.
************************************************************************
(3 10)                  /Mass/refers to the ball
This node codes 11 documents.
************************************************************************
(3 11)                  /Mass/how much of it there is
This node codes 2 documents.
************************************************************************
(3 12)                  /Mass/more mass=slower
This node codes 14 documents.
************************************************************************
(3 13)                  /Mass/doesn't change speed
This node codes 4 documents.
************************************************************************
(3 14)                  /Mass/more mass=faster
This node codes 15 documents.
************************************************************************
(3 15)                  /Mass/makes paddle sag
This node codes 16 documents.
************************************************************************
(3 16)                  /Mass/forces downward
This node codes 6 documents.
************************************************************************
(3 17)                  /Mass/doesn't make ball go further
This node codes 2 documents.
************************************************************************
(3 18)                  /Mass/has matter, density
This node codes 4 documents.
************************************************************************
(3 19)                  /Mass/makes less bouncy
This node codes 2 documents.
************************************************************************
(3 20)                  /Mass/makes ball lighter
This node codes 2 documents.
************************************************************************
(3 21)                  /Mass/more mass=more feel
This node codes 1 document.
************************************************************************
(3 22)                  /Mass/everything around you
This node codes 2 documents.
************************************************************************
(3 23)                  /Mass/force of ball or paddle
This node codes 1 document.
************************************************************************
(3 24)                  /Mass/related to gravity
This node codes 1 document.
************************************************************************
(3 25)                  /Mass/changes speed
This node codes 2 documents.
************************************************************************
(3 26)                  /Mass/affects how paddle moves
This node codes 1 document.
************************************************************************
(3 27)                  /Mass/mass and gravity are different
This node codes 2 documents.
************************************************************************
```

```
(3 28)                  /Mass/= force
This node codes 1 document.
************************************************************************
(3 29)                  /Mass/a sail
This node codes 1 document.
************************************************************************
(4)                     /Sees
This node codes 0 documents.
************************************************************************
(4 1)                   /Sees/multiple balls, color change
This node codes 11 documents.
************************************************************************
(4 1 1)                 /Sees/multiple balls, color change/indicate
speed
This node codes 4 documents.
************************************************************************
(4 2)                   /Sees/bent paddle
This node codes 21 documents.
************************************************************************
(4 3)                   /Sees/straight paddle
This node codes 20 documents.
************************************************************************
(4 3 1)                 /Sees/straight paddle/paddle is harder, stiffer
This node codes 4 documents.
************************************************************************
(4 4)                   /Sees/hanging or V paddle
This node codes 27 documents.
************************************************************************
(4 4 1)                 /Sees/hanging or V paddle/3 makes biggest V
This node codes 4 documents.
************************************************************************
(4 4 2)                 /Sees/hanging or V paddle/goes down farther
This node codes 1 document.
************************************************************************
(4 5)                   /Sees/leaves at the bottom of screen
This node codes 1 document.
************************************************************************
(4 6)                   /Sees/makes dizzy
This node codes 1 document.
************************************************************************
(4 13)                  /Sees/ball sticks to paddle
This node codes 12 documents.
************************************************************************
(5)                     /Feels
This node codes 0 documents.
************************************************************************
(5 1)                   /Feels/feel it more
This node codes 9 documents.
************************************************************************
(5 2)                   /Feels/feels good
This node codes 5 documents.
************************************************************************
(5 3)                   /Feels/can't feel anything
This node codes 1 document.
************************************************************************
(5 4)                   /Feels/can feel something
This node codes 7 documents.
```

```
************************************************************************
(5 5)                   /Feels/vibration when ball hits
This node codes 7 documents.
************************************************************************
(5 6)                   /Feels/feel push, bounce
This node codes 8 documents.
************************************************************************
(5 7)                   /Feels/feel it less
This node codes 4 documents.
************************************************************************
(5 8)                   /Feels/feels lighter
This node codes 10 documents.
************************************************************************
(5 10)                  /Feels/feels heavy
This node codes 16 documents.
************************************************************************
(6)                     /Motion
This node codes 0 documents.
************************************************************************
(6 1)                   /Motion/Speed
This node codes 3 documents.
************************************************************************
(6 1 3)                 /Motion/Speed/more bounciness = more speed
This node codes 2 documents.
************************************************************************
(6 1 5)                 /Motion/Speed/same as before
This node codes 1 document.
************************************************************************
(6 1 6)                 /Motion/Speed/fast
This node codes 32 documents.
************************************************************************
(6 1 6 1)               /Motion/Speed/fast/faster coming down
This node codes 21 documents.
************************************************************************
(6 1 6 2)               /Motion/Speed/fast/as fast as 3 and 4
This node codes 1 document.
************************************************************************
(6 1 6 4)               /Motion/Speed/fast/4 is fastest
This node codes 10 documents.
************************************************************************
(6 1 6 5)               /Motion/Speed/fast/goes up faster
This node codes 12 documents.
************************************************************************
(6 1 6 6)               /Motion/Speed/fast/1 is fastest
This node codes 3 documents.
************************************************************************
(6 1 6 7)               /Motion/Speed/fast/3 is fastest
This node codes 8 documents.
************************************************************************
(6 1 8)                 /Motion/Speed/medium speed
This node codes 12 documents.
************************************************************************
(6 1 15)                /Motion/Speed/slow
This node codes 23 documents.
************************************************************************
(6 1 15 1)              /Motion/Speed/slow/slower going up
This node codes 12 documents.
```

```
*************************************************************************
(6 1 15 2)              /Motion/Speed/slow/slower coming down
This node codes 10 documents.
*************************************************************************
(6 1 15 3)              /Motion/Speed/slow/long time to come back
This node codes 17 documents.
*************************************************************************
(6 1 15 4)              /Motion/Speed/slow/2 is slowest
This node codes 1 document.
*************************************************************************
(6 1 15 5)              /Motion/Speed/slow/slows down over time
This node codes 4 documents.
*************************************************************************
(6 1 15 6)              /Motion/Speed/slow/slow first-inertia
This node codes 1 document.
*************************************************************************
(6 2)                   /Motion/Distance
This node codes 0 documents.
*************************************************************************
(6 2 1)                 /Motion/Distance/controls speed
This node codes 2 documents.
*************************************************************************
(6 2 7)                 /Motion/Distance/goes far, high
This node codes 22 documents.
*************************************************************************
(6 2 12)                /Motion/Distance/doesn't go very high
This node codes 15 documents.
*************************************************************************
(6 3)                   /Motion/Floating
This node codes 1 document.
*************************************************************************
(6 4)                   /Motion/bounce/elasticity/inertia
This node codes 4 documents.
*************************************************************************
(6 4 1)                 /Motion/bounce/elasticity/inertia/2 is the
bounciest
This node codes 16 documents.
*************************************************************************
(6 4 2)                 /Motion/bounce/elasticity/inertia/4 is least
bouncy
This node codes 11 documents.
*************************************************************************
(6 4 3)                 /Motion/bounce/elasticity/inertia/Bouncy
This node codes 23 documents.
*************************************************************************
(6 4 4)                 /Motion/bounce/elasticity/inertia/elastic force
This node codes 15 documents.
*************************************************************************
(6 4 5)                 /Motion/bounce/elasticity/inertia/not very
bouncy
This node codes 20 documents.
*************************************************************************
(6 4 6)                 /Motion/bounce/elasticity/inertia/bounces longer
This node codes 3 documents.
*************************************************************************
(6 4 9)                 /Motion/bounce/elasticity/inertia/1 is bounciest
This node codes 1 document.
```

```
************************************************************************
(6 4 11)                /Motion/bounce/elasticity/inertia/in the middle
This node codes 1 document.
************************************************************************
(6 4 22)                /Motion/bounce/elasticity/inertia/inertia
This node codes 3 documents.
************************************************************************
(6 5)                   /Motion/acceleration
This node codes 3 documents.
************************************************************************
(6 6)                   /Motion/doesn't keep bouncing
This node codes 1 document.
************************************************************************
(6 7)                   /Motion/can't control ball
This node codes 1 document.
************************************************************************
(7)                     /Force
This node codes 1 document.
************************************************************************
(7 1)                   /Force/don't have to hit as hard
This node codes 17 documents.
************************************************************************
(7 2)                   /Force/force controls speed
This node codes 12 documents.
************************************************************************
(7 3)                   /Force/force controls distance
This node codes 14 documents.
************************************************************************
(7 4)                   /Force/the force is the same
This node codes 5 documents.
************************************************************************
(7 5)                   /Force/harder to move
This node codes 20 documents.
************************************************************************
(7 6)                   /Force/forcing me back
This node codes 3 documents.
************************************************************************
(7 7)                   /Force/drags me down
This node codes 3 documents.
************************************************************************
(7 8)                   /Force/hit it hard
This node codes 25 documents.
************************************************************************
(7 9)                   /Force/ball moves mouse/paddle
This node codes 4 documents.
************************************************************************
(7 10)                  /Force/the force is less
This node codes 4 documents.
************************************************************************
(7 11)                  /Force/need to hit it hard
This node codes 23 documents.
************************************************************************
(7 12)                  /Force/force controls bounces
This node codes 5 documents.
************************************************************************
(7 13)                  /Force/didn't hit hard
This node codes 14 documents.
```

```
************************************************************************
(7 14)                  /Force/more force creates more force
This node codes 3 documents.
************************************************************************
(7 15)                  /Force/ball hits paddle hard
This node codes 2 documents.
************************************************************************
(7 16)                  /Force/a push or pull
This node codes 8 documents.
************************************************************************
(7 17)                  /Force/gravity
This node codes 5 documents.
************************************************************************
(7 18)                  /Force/makes us move
This node codes 1 document.
************************************************************************
(7 19)                  /Force/strong object
This node codes 1 document.
************************************************************************
(7 20)                  /Force/coerce
This node codes 3 documents.
************************************************************************
(7 21)                  /Force/protecting
This node codes 2 documents.
************************************************************************
(7 22)                  /Force/momentum
This node codes 1 document.
************************************************************************
(8)                     /Weight
This node codes 0 documents.
************************************************************************
(8 1)                   /Weight/heavi(er), heaviness
This node codes 27 documents.
************************************************************************
(8 2)                   /Weight/3 is heaviest
This node codes 8 documents.
************************************************************************
(8 3)                   /Weight/bigger
This node codes 1 document.
************************************************************************
(8 4)                   /Weight/causes paddle to sink
This node codes 10 documents.
************************************************************************
(8 5)                   /Weight/heaviness makes it slower
This node codes 1 document.
************************************************************************
(8 6)                   /Weight/heaviness makes it (fall) faster
This node codes 3 documents.
************************************************************************
(8 7)                   /Weight/damping and/or stiffness make it heavier
This node codes 2 documents.
************************************************************************
(8 8)                   /Weight/more makes it bouncier
This node codes 2 documents.
************************************************************************
(8 9)                   /Weight/middle weight
This node codes 3 documents.
```

```
************************************************************************
(8 10)                  /Weight/4 is heaviest
This node codes 6 documents.
************************************************************************
(8 11)                  /Weight/weight=mass
This node codes 12 documents.
************************************************************************
(8 12)                  /Weight/refers to ball
This node codes 1 document.
************************************************************************
(8 13)                  /Weight/weight=force in things
This node codes 2 documents.
************************************************************************
(8 14)                  /Weight/light(er)
This node codes 15 documents.
************************************************************************
(8 14 1)                /Weight/light(er)/lighter=easier to bounce
This node codes 2 documents.
************************************************************************
(8 15)                  /Weight/=matter
This node codes 1 document.
************************************************************************
(8 16)                  /Weight/=pull of gravity
This node codes 7 documents.
************************************************************************
(8 17)                  /Weight/how much person weighs
This node codes 1 document.
************************************************************************
(8 21)                  /Weight/mass & gravity = heaviest
This node codes 15 documents.
************************************************************************
(8 21 1)                /Weight/mass & gravity = heaviest/50-50
mass&gravity
This node codes 2 documents.
************************************************************************
(8 21 2)                /Weight/mass & gravity = heaviest/lots of
gravity = a lot of weight
This node codes 2 documents.
************************************************************************
(8 21 3)                /Weight/mass & gravity = heaviest/weight depends
on gravity
This node codes 1 document.
************************************************************************
(10)                    /Repeated experiment
This node codes 19 documents.
************************************************************************
(11)                    /Metaphors and similes
This node codes 1 document.
************************************************************************
(11 1)                  /Metaphors and similes/like ping pong
This node codes 3 documents.
************************************************************************
(11 2)                  /Metaphors and similes/like trampoline
This node codes 3 documents.
************************************************************************
(11 3)                  /Metaphors and similes/ball doesn't want to go
away
```

```
This node codes 2 documents.
************************************************************************
(11 4)                  /Metaphors and similes/like being shot at
This node codes 1 document.
************************************************************************
(11 5)                  /Metaphors and similes/like a slingshot
This node codes 8 documents.
************************************************************************
(11 6)                  /Metaphors and similes/pushed into a hole
This node codes 1 document.
************************************************************************
(11 7)                  /Metaphors and similes/feels like moving 100#
cat
This node codes 1 document.
************************************************************************
(11 8)                  /Metaphors and similes/feels like weight-lifting
This node codes 1 document.
************************************************************************
(11 9)                  /Metaphors and similes/like a boulder
This node codes 1 document.
************************************************************************
(11 10)                 /Metaphors and similes/like a bomb
This node codes 1 document.
************************************************************************
(11 11)                 /Metaphors and similes/like a bulldozer
This node codes 1 document.
************************************************************************
(11 12)                 /Metaphors and similes/like a pebble
This node codes 1 document.
************************************************************************
(11 13)                 /Metaphors and similes/like the Roadrunner
This node codes 1 document.
************************************************************************
(11 14)                 /Metaphors and similes/like a catapult
This node codes 1 document.
************************************************************************
(11 15)                 /Metaphors and similes/ball doesn't let paddle
hit it
This node codes 1 document.
************************************************************************
(11 16)                 /Metaphors and similes/like water
This node codes 1 document.
************************************************************************
(11 17)                 /Metaphors and similes/like paddleball
This node codes 2 documents.
************************************************************************
(11 18)                 /Metaphors and similes/like a torpedo
This node codes 1 document.
************************************************************************
(11 19)                 /Metaphors and similes/like a curtain
This node codes 1 document.
************************************************************************
(11 20)                 /Metaphors and similes/like jumping on the bed
This node codes 1 document.
************************************************************************
(11 21)                 /Metaphors and similes/like a comet going up
This node codes 1 document.
```

```
************************************************************************
(11 22)                 /Metaphors and similes/like the speed of light
This node codes 1 document.
************************************************************************
(11 23)                 /Metaphors and similes/like a spring
This node codes 2 documents.
************************************************************************
(11 24)                 /Metaphors and similes/like a cub and its mom
This node codes 1 document.
************************************************************************
(11 25)                 /Metaphors and similes/like being at mall with
adult
This node codes 1 document.
************************************************************************
(11 26)                 /Metaphors and similes/like a hammock
This node codes 1 document.
************************************************************************
(11 27)                 /Metaphors and similes/like a rubber band
This node codes 3 documents.
************************************************************************
(11 28)                 /Metaphors and similes/compare to various kinds
of balls
This node codes 3 documents.
************************************************************************
(11 29)                 /Metaphors and similes/like lightning
This node codes 1 document.
************************************************************************
(11 30)                 /Metaphors and similes/immune to gravity-goes
far
This node codes 1 document.
************************************************************************
(11 32)                 /Metaphors and similes/like a magnet
This node codes 1 document.
************************************************************************
(11 33)                 /Metaphors and similes/standing against wall
This node codes 1 document.
************************************************************************
(11 34)                 /Metaphors and similes/like throwing a rock
This node codes 1 document.
************************************************************************
(12)                    /attitudes and learning
This node codes 0 documents.
************************************************************************
(12 1)                  /attitudes and learning/liked it, fun, cool,
etc.
This node codes 34 documents.
************************************************************************
(12 2)                  /attitudes and learning/like a game, playing
This node codes 11 documents.
************************************************************************
(12 3)                  /attitudes and learning/like science
This node codes 6 documents.
************************************************************************
(12 4)                  /attitudes and learning/like learning
This node codes 5 documents.
************************************************************************
(12 5)                  /attitudes and learning/likes doing experiments
```

```
This node codes 6 documents.
************************************************************************
(12 6)                  /attitudes and learning/writing helps me learn
This node codes 1 document.
************************************************************************
(12 7)                  /attitudes and learning/liked being able to feel
changes
This node codes 5 documents.
************************************************************************
(12 8)                  /attitudes and learning/not good at
mass/gravity/science
This node codes 1 document.
************************************************************************
(12 9)                  /attitudes and learning/makes science easier to
learn
This node codes 1 document.
************************************************************************
(12 10)                 /attitudes and learning/learned what mass and
gravity are
This node codes 4 documents.
************************************************************************
(12 11)                 /attitudes and learning/liked getting out of
class
This node codes 1 document.
************************************************************************
(13)                    /Equality/inequality/opposites
This node codes 16 documents.
************************************************************************
(13 1)                  /Equality/inequality/opposites/results of 5 & 6
similar
This node codes 1 document.
************************************************************************
(14)                    /math/measurement/units
This node codes 6 documents.
************************************************************************
(15)                    /FF
This node codes 17 documents.
************************************************************************
(15 1)                  /FF/have to hold paddle
This node codes 4 documents.
************************************************************************
(15 2)                  /FF/Ball slips off paddle
This node codes 1 document.
************************************************************************
(15 3)                  /FF/hand feels weird
This node codes 1 document.
************************************************************************
(15 4)                  /FF/tired
This node codes 1 document.
************************************************************************
(16)                    /no FF
This node codes 17 documents.
************************************************************************
(16 1)                  /no FF/no need to hold mouse
This node codes 2 documents.
************************************************************************
(20)                    /base data
```

```
This node codes 0 documents.
************************************************************************
(20 1)                  /base data/CONTROL
This node codes 0 documents.
************************************************************************
(20 1 1)                /base data/CONTROL/Y
This node codes 17 documents.
************************************************************************
(20 1 2)                /base data/CONTROL/N
This node codes 17 documents.
************************************************************************
(20 2)                  /base data/GENDER
This node codes 0 documents.
************************************************************************
(20 2 1)                /base data/GENDER/F
This node codes 16 documents.
************************************************************************
(20 2 2)                /base data/GENDER/M
This node codes 18 documents.
************************************************************************
(20 3)                  /base data/SCHOOL
This node codes 0 documents.
************************************************************************
(20 3 1)                /base data/SCHOOL/C
This node codes 15 documents.
************************************************************************
(20 3 2)                /base data/SCHOOL/B
This node codes 8 documents.
************************************************************************
(20 3 3)                /base data/SCHOOL/D
This node codes 11 documents.
************************************************************************
(20 4)                  /base data/PREF
This node codes 0 documents.
************************************************************************
(20 4 1)                /base data/PREF/VA
This node codes 5 documents.
************************************************************************
(20 4 2)                /base data/PREF/V
This node codes 21 documents.
************************************************************************
(20 4 3)                /base data/PREF/VAH
This node codes 1 document.
************************************************************************
(20 4 4)                /base data/PREF/H
This node codes 1 document.
************************************************************************
(20 4 5)                /base data/PREF/A
This node codes 5 documents.
************************************************************************
(20 4 6)                /base data/PREF/HV
This node codes 1 document.
************************************************************************
(20 5)                  /base data/POSTCOR
This node codes 0 documents.
************************************************************************
(20 5 1)                /base data/POSTCOR/7
```

```
This node codes 4 documents.
************************************************************************
(20 5 2)                /base data/POSTCOR/6
This node codes 7 documents.
************************************************************************
(20 5 3)                /base data/POSTCOR/5
This node codes 8 documents.
************************************************************************
(20 5 4)                /base data/POSTCOR/8
This node codes 3 documents.
************************************************************************
(20 5 5)                /base data/POSTCOR/10
This node codes 4 documents.
************************************************************************
(20 5 6)                /base data/POSTCOR/3
This node codes 2 documents.
************************************************************************
(20 5 7)                /base data/POSTCOR/4
This node codes 4 documents.
************************************************************************
(20 5 8)                /base data/POSTCOR/2
This node codes 1 document.
************************************************************************
(20 5 9)                /base data/POSTCOR/9
This node codes 1 document.
************************************************************************
(20 6)                  /base data/POSTINC
This node codes 0 documents.
************************************************************************
(20 6 1)                /base data/POSTINC/4
This node codes 6 documents.
************************************************************************
(20 6 2)                /base data/POSTINC/0
This node codes 1 document.
************************************************************************
(20 6 3)                /base data/POSTINC/3
This node codes 12 documents.
************************************************************************
(20 6 4)                /base data/POSTINC/2
This node codes 9 documents.
************************************************************************
(20 6 5)                /base data/POSTINC/1
This node codes 4 documents.
************************************************************************
(20 6 6)                /base data/POSTINC/5
This node codes 1 document.
************************************************************************
(20 6 7)                /base data/POSTINC/7
This node codes 1 document.
************************************************************************
(20 7)                  /base data/POST1A
This node codes 0 documents.
************************************************************************
(20 7 1)                /base data/POST1A/1
This node codes 27 documents.
************************************************************************
(20 7 2)                /base data/POST1A/0
```

```
This node codes 7 documents.
************************************************************************
(20 8)                  /base data/POST1B
This node codes 0 documents.
************************************************************************
(20 8 1)                /base data/POST1B/1
This node codes 24 documents.
************************************************************************
(20 8 2)                /base data/POST1B/0
This node codes 10 documents.
************************************************************************
(20 9)                  /base data/POST1C
This node codes 0 documents.
************************************************************************
(20 9 1)                /base data/POST1C/0
This node codes 31 documents.
************************************************************************
(20 9 2)                /base data/POST1C/1
This node codes 3 documents.
************************************************************************
(20 10)                 /base data/POST1D
This node codes 0 documents.
************************************************************************
(20 10 1)               /base data/POST1D/0
This node codes 29 documents.
************************************************************************
(20 10 2)               /base data/POST1D/1
This node codes 5 documents.
************************************************************************
(20 11)                 /base data/POST2A
This node codes 0 documents.
************************************************************************
(20 11 1)               /base data/POST2A/0
This node codes 18 documents.
************************************************************************
(20 11 2)               /base data/POST2A/1
This node codes 16 documents.
************************************************************************
(20 12)                 /base data/POST2B
This node codes 0 documents.
************************************************************************
(20 12 1)               /base data/POST2B/1
This node codes 26 documents.
************************************************************************
(20 12 2)               /base data/POST2B/0
This node codes 8 documents.
************************************************************************
(20 13)                 /base data/POST2C
This node codes 0 documents.
************************************************************************
(20 13 1)               /base data/POST2C/0
This node codes 30 documents.
************************************************************************
(20 13 2)               /base data/POST2C/1
This node codes 4 documents.
************************************************************************
(20 14)                 /base data/POST2D
```

```
This node codes 0 documents.
************************************************************************
(20 14 1)               /base data/POST2D/0
This node codes 34 documents.
************************************************************************
(20 15)                 /base data/POST3A
This node codes 0 documents.
************************************************************************
(20 15 1)               /base data/POST3A/1
This node codes 4 documents.
************************************************************************
(20 15 2)               /base data/POST3A/0
This node codes 30 documents.
************************************************************************
(20 16)                 /base data/POST3B
This node codes 0 documents.
************************************************************************
(20 16 1)               /base data/POST3B/0
This node codes 14 documents.
************************************************************************
(20 16 2)               /base data/POST3B/1
This node codes 20 documents.
************************************************************************
(20 17)                 /base data/POST3C
This node codes 0 documents.
************************************************************************
(20 17 1)               /base data/POST3C/1
This node codes 19 documents.
************************************************************************
(20 17 2)               /base data/POST3C/0
This node codes 14 documents.
************************************************************************
(20 17 3)               /base data/POST3C/10
This node codes 1 document.
************************************************************************
(20 18)                 /base data/POST3D
This node codes 0 documents.
************************************************************************
(20 18 1)               /base data/POST3D/0
This node codes 31 documents.
************************************************************************
(20 18 2)               /base data/POST3D/1
This node codes 3 documents.
************************************************************************
(20 19)                 /base data/POST4A
This node codes 0 documents.
************************************************************************
(20 19 1)               /base data/POST4A/1
This node codes 12 documents.
************************************************************************
(20 19 2)               /base data/POST4A/0
This node codes 22 documents.
************************************************************************
(20 20)                 /base data/POST4B
This node codes 0 documents.
************************************************************************
(20 20 1)               /base data/POST4B/0
```

```
This node codes 18 documents.
*************************************************************************
(20 20 2)               /base data/POST4B/1
This node codes 16 documents.
*************************************************************************
(20 21)                 /base data/POST4C
This node codes 0 documents.
*************************************************************************
(20 21 1)               /base data/POST4C/1
This node codes 12 documents.
*************************************************************************
(20 21 2)               /base data/POST4C/0
This node codes 22 documents.
*************************************************************************
(20 22)                 /base data/POST4D
This node codes 0 documents.
*************************************************************************
(20 22 1)               /base data/POST4D/1
This node codes 8 documents.
*************************************************************************
(20 22 2)               /base data/POST4D/0
This node codes 26 documents.
*************************************************************************
(20 23)                 /base data/POST5A
This node codes 0 documents.
*************************************************************************
(20 23 1)               /base data/POST5A/0
This node codes 30 documents.
*************************************************************************
(20 23 2)               /base data/POST5A/1
This node codes 4 documents.
*************************************************************************
(20 24)                 /base data/POST5B
This node codes 0 documents.
*************************************************************************
(20 24 1)               /base data/POST5B/1
This node codes 24 documents.
*************************************************************************
(20 24 2)               /base data/POST5B/0
This node codes 10 documents.
*************************************************************************
(20 25)                 /base data/POST5C
This node codes 0 documents.
*************************************************************************
(20 25 1)               /base data/POST5C/1
This node codes 8 documents.
*************************************************************************
(20 25 2)               /base data/POST5C/0
This node codes 26 documents.
*************************************************************************
(20 26)                 /base data/POST5D
This node codes 0 documents.
*************************************************************************
(20 26 1)               /base data/POST5D/0
This node codes 16 documents.
*************************************************************************
(20 26 2)               /base data/POST5D/1
```

```
This node codes 18 documents.
************************************************************************
(20 27)                 /base data/POST6A
This node codes 0 documents.
************************************************************************
(20 27 1)               /base data/POST6A/0
This node codes 29 documents.
************************************************************************
(20 27 2)               /base data/POST6A/1
This node codes 5 documents.
************************************************************************
(20 28)                 /base data/POST6B
This node codes 0 documents.
************************************************************************
(20 28 1)               /base data/POST6B/1
This node codes 18 documents.
************************************************************************
(20 28 2)               /base data/POST6B/0
This node codes 16 documents.
************************************************************************
(20 29)                 /base data/POST6C
This node codes 0 documents.
************************************************************************
(20 29 1)               /base data/POST6C/0
This node codes 15 documents.
************************************************************************
(20 29 2)               /base data/POST6C/1
This node codes 19 documents.
************************************************************************
(20 30)                 /base data/POST6D
This node codes 0 documents.
************************************************************************
(20 30 1)               /base data/POST6D/0
This node codes 28 documents.
************************************************************************
(20 30 2)               /base data/POST6D/1
This node codes 6 documents.
************************************************************************
(20 31)                 /base data/GAMEPLAY
This node codes 0 documents.
************************************************************************
(20 31 1)               /base data/GAMEPLAY/3
This node codes 11 documents.
************************************************************************
(20 31 2)               /base data/GAMEPLAY/2
This node codes 8 documents.
************************************************************************
(20 31 3)               /base data/GAMEPLAY/1
This node codes 11 documents.
************************************************************************
(20 31 4)               /base data/GAMEPLAY/0
This node codes 1 document.
************************************************************************
(20 31 5)               /base data/GAMEPLAY/4
This node codes 3 documents.
```

Appendix D: Parental and Subject Consent Forms

Parental Consent Form

San Diego State University and University of San Diego
Parental Permission/Informed Consent to Participate in Research
(The Effect of Force Feedback on Student Reasoning about Mass and Gravity)

You are being asked to allow your child to participate in a research study. Before you give your permission for your child to participate, it is important that you read the following information and ask as many questions as necessary to be sure you understand what your child will be asked to do.

Investigators:
Linda Bussell, graduate student. College of Education, San Diego State University and School of Education, University of San Diego

Dr. Susan Zgliczynski, faculty advisor. School of Education, University of San Diego

Purpose of the Study:
The purpose of this study is to see if "force feedback" in a software program may affect a child's understanding of science concepts like mass and gravity. Force feedback means that the child can feel things in the program, as well as see them. Some children will use a special mouse that allows them to feel changes in force and weight. Others will use the same software program and mouse without force feedback, to determine whether the force feedback makes a difference.

Approximately 30 children will participate in this study. They must be able to read, write, and speak English because the written directions and the interview questions will be in English.

Description of the Study:
Fifth grade students are being recruited for this study through elementary schools in San Diego County. Your child is being asked to participate because your child's teacher thinks it will be a worthwhile experience for him or her. If you agree to allow your child to participate, he/she will be asked to use a computer-based simulation of paddleball to do some experiments. This will take about 30 minutes. The work with the computer will take place in a quiet room outside of the classroom such as a conference room, testing room, to be determined by the principal, teacher or other school administrator. The child will be asked to do a set of experiments that involve changing the mass (density) of the ball and the gravity acting on the ball. Participants will be asked to record their observations. They will be asked questions about their observations, and will be asked to make predictions. They will be asked questions about how they like the software.

Your child's participation in this study is completely voluntary. Your child will be audio recorded while he/she uses the software and answers interview questions.

What is Experimental in this Study:
None of the procedures used in this study are experimental in nature. The only experimental aspect of this study is the gathering of information for the purpose of analysis.

Risks or Discomforts:
Your child may become tired or frustrated when trying to complete a task or activity that is being measured. If your child begins to feel uncomfortable with the required tasks, he/she may stop participating in the study, either temporarily or permanently.

Benefits of the Study:
Your child will be given the opportunity to learn about mass and gravity through a software program. There is no guarantee, however, that you or your child will receive any benefits from this study.

The results of the study may aid those who create educational software to design more effective environments for learning.

Confidentiality:
To protect your child's confidentiality, your child's name will not be shared with anyone, unless required by law. We will store written and recorded information about how your child uses the computer program. Only the principal investigator and research assistant will have access to this data. Data will be kept for a minimum of five years. Your child's information will be kept confidential until it is destroyed.

Incentives to Participate:
Your child will not be paid for his/her participation.

Voluntary Nature of Participation:
Participation in this study is voluntary. Your decision of whether or not to allow your child to participate will not prejudice your future relations with your child's school, San Diego State University or the University of San Diego. If you decide to allow your child to participate, you are free to withdraw your consent and to discontinue his/her participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Questions about the Study:
If you have questions regarding your child's rights as a human subject and participant in this study, you may call the Committee on Protection of Human Subjects at University of San Diego for information. The telephone number of the University is (619) 260-4600. You may also write to the Committee at: USD Institutional Review Board, University of San Diego, 5998 Alcalá Park, San Diego, CA 92110-2492. Alternatively, you may contact the Institutional Review Board at San Diego State University for information. The telephone number of the Committee is 619-594-6622. You may also write to the Committee at: SDSU Institutional Review Board, 5500 Campanile Drive, San Diego, CA 92182-1643.

You may contact the Principle Investigator by phone at (619) 275-5243. You may contact the Principle Investigator in writing at: Linda Bussell, PO Box 82928, San Diego, CA 92138-2928 or by email at lbussell@san.rr.com.

Agreement:

The San Diego State University and University of San Diego Institutional Review Boards have approved this consent form as signified by the Committee's stamp. The consent form must be reviewed annually and expires on the date indicated on the stamp.

Your signature below indicates that you have read the information in this document and have had a chance to ask any questions you have about the study. Your signature also indicates that you agree to allow your child to be in the study and have been told that you can change your mind and withdraw your consent to participate at any time. You have been given a copy of this agreement. You have been told that by signing this consent document you are not giving up any of your legal rights.

Name of Child (please print)

Signature of Parent or Guardian Date

Signature of Investigator Date

Subject Consent Form

San Diego State University and University of San Diego
Assent to Participate in Research
(The Effect of Force Feedback on Student Reasoning about Mass and Gravity)

1. My name is Linda Bussell.

2. We are asking you to take part in a research study. We are trying to learn more about how to make learning on computers better.

3. If you agree to be in this study, you will be asked to spend about 30 minutes doing a science experiment on the computer. After you use the computer, you will be asked some questions about what you have learned. We will record your answers on a tape recorder.

4. You may get tired or frustrated during the computer lesson. If you do, please tell me right away, and you will be able stop.

5. By participating in this study, we hope you'll learn a little about mass and gravity. You will have an opportunity to use a software program and a different kind of computer mouse that you probably haven't tried before.

6. Please talk to your parents about this study before you decide whether to participate. We will also ask your parents if it is all right with them for you to take part in this study. If your parents say that you can be in the study, you can still decide not to participate.

7. You can ask me any questions that you have about this study and I will try to answer them for you. If you have questions that you think of later, you can call me at 619-275-5243.

8. Taking part in this study is up to you. No one will be upset if you don't want to participate. If you decide to participate, you can also change your mind and stop any time you want.

Please mark one of the choices below:

____ **No, I do not want to be in this study** ____ **Yes, I want to be in this study**

______________________________ ____________
Write your name here **Date**

______________________________ ____________
Project Representative **Date**

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The Effect of Force Feedback on Student Reasoning about Gravity, Mass, Force and Motion

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Immersion Corporation	Agreed to and Accepted by:
By:	By:
Name: Patrick Reutens	Name: Linda Bussell
Title: Sr. VP Corporate Development & Legal Affairs	Title: AUTHOR
Date: 4/1/04	Date: 3/30/04