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Bridging the Gap in Physics Education

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by

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Bridging the Gap in Physics Education

by

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Abstract

Over the past few years there has been a growing interest in the possible benefits of computer simulations in physics education. However, very little research has been conducted on how computer simulations can actually be integrated into a physics program (Zacharia & Anderson, 2003. This research investigated the effects of computer simulations on the development of accurate mental models when used in conjunction with traditional laboratory-based experiments. Since laboratory experiments can often have results that are very difficult to observe, these results only become evident to the trained eye of an expert. Computer simulations are able to present phenomena free of the normal distractions that occur during traditional laboratory-based experiments. Through the analysis of posttests, questionnaires, and student interviews conducted in a high school physics class, it was shown that when computer simulations are used in conjunction with traditional laboratory activities students appear to make accurate revisions to their naïve mental models of motion. The results also indicate that the majority of the students believe that the computer simulations assisted in the clarification of the laboratory results and allowed them to more fully understand the theoretical concepts being presented in the laboratory investigation.

Chapter 1: Introduction

Problem Statement

In physics education, students often have difficulties in developing accurate mental models of abstract concepts. It is the goal of this report to investigate the effects of computer simulations on the development of accurate mental models when the computer simulations are used in conjunction with traditional laboratory-based investigations.

Significance of the Problem

Over the past few years there has been a growing interest in the possible benefits of the use of computer simulations in physics education. However, very little research has been conducted on how computer simulations can actually be integrated into a physics program (Zacharia & Anderson, 2003). This report seeks to investigate the innovative role that computer simulations can play in physics education.

Traditional physics education focuses on two main methods of instruction: direct classroom lecture and hands-on laboratory investigations. Classroom lecture is typically aimed at presenting the facts, laws, and beliefs of scientific theory. Laboratory investigations then attempt to find evidence to support these theories. It is well documented that hands-on laboratory investigations are an integral part of physics education; however, there often exists a gap between the truth according to theory and what is observed within a laboratory investigation. As a result, the laboratory investigation tends to reinforce the naïve mental models of motion that the students previously obtained through interaction with a world dominated by the latent effects of friction and gravity. Physics educators are faced with the difficult task of eliminating the gap between theory and perceived reality within students' mental models of motion.

Rationale

Computer simulations are able to present phenomena free of the normal distractions that occur during traditional laboratory-based experiments. Ideal environments, such as frictionless surfaces, perfect vacuums, and gravity-free classrooms, are often used to simplify physics instruction so that students gain an understanding of theory. However, these ideal environments can never exist within a hands-on laboratory investigation. It is possible to create these ideal environments within a computer simulation. Due to this fact, a computer simulation may act as a bridge between scientific theory and perceived reality, when it is implemented in conjunction with a hands-on investigation.

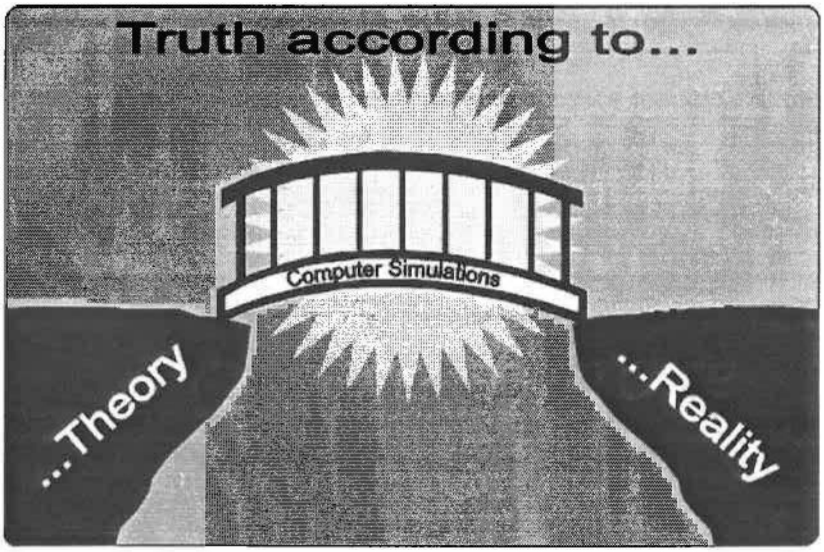


Figure 1. Computer simulations may act as a bridge between theory and perceived reality.

Definition of Terms

The definitions of the terms that are used in this report vary slightly throughout educational literature. To avoid misinterpretation the following definitions should be used throughout this report. A computer simulation refers to a computer program that attempts to simulate an abstract model of a particular system. A mental model is an explanation in one's thought process for how something works in the real world, a kind of internal symbol or representation of external reality. Traditional laboratory-based investigations are any classroom activity utilizing hands-on equipment for the purpose of learning. Truth according to reality is what an observer perceives to be true in accordance with his/her observations and interpretations of the world. Truth according to theory is a logically self-consistent model or framework for describing the behavior of a natural phenomenon, which originates from and/or is supported by experimental evidence. Regular classroom instruction is any pedagogical practices that do not involve the simultaneous use of computer simulations and hands-on laboratory equipment, examples include direct lecture and traditional laboratory investigations

Summary

Under the premise that computer simulations can act as a bridge between theory and perceived reality, this report investigates the following specific questions: Based on everyday experiences, do students develop accurate mental models of motion? Why are accurate mental models important in physics education? After regular classroom instruction, are students able to revise their naïve mental models of motion? Do computer simulations aid in the revision of naïve mental models of motion? If a computer simulation is used in conjunction with a laboratory experiment, will a student more effectively revise his/her naïve mental models of motion? To provide an understanding of what has been studied previously, this report begins with a review of the literature pertinent to each question.

Chapter 2: Literature Review

Mental Model Theory and Naïve Theories of Motion

"Reasoning is a process of thought that yields a conclusion from percepts, thoughts, or assertions" (Johnson-Laird, 1999, p. 110). Johnson-Laird's mental model theory postulates that "reasoners use the meaning of assertions (their intentions) and general knowledge to construct models of the possibilities compatible with the assertions (their extensions)" (Goodwin & Johnson-Laird, 2005, p. 473). These models, developed from the extensions of the assertions, are then integrated to form a single mental model that can be used to formulate a prediction or a conclusion (Goodwin & Johnson-Laird, 2005). The accuracy of predictions or conclusions in physics is dependent upon the accuracy of the mental model, and in turn the accuracy of the mental model is dependent upon the degree of accuracy of the original percepts, thoughts, and assertions.

Unfortunately, on the basis of their everyday experiences, people develop remarkably well-articulated naïve theories of motion (McCloskey, 1984). These naïve theories of motion are constructed through interaction with a world dominated by the effects of friction and gravity. The presence of these forces is so universal that their effects are considered to be a normal part of the behavior of an object in motion. As a consequence, the mental models that we develop when interacting with this world are inherently flawed.

A team of researchers from John's Hopkins University investigated students' use of what they called the naïve impetus theories (McCloskey, 1984). These theories provide an explanation for the behavior of moving objects by claiming that an object set into motion will continue in motion due to an internal force. Over a period of time this internal force is lost as a result of dissipation (McCloskey, 1984). This explanation, though functional for predicting the behavior of a ball rolling across a floor, will lead to drastically inaccurate predictions if applied generally to other situations. McCloskey found that 52% of his 48 subjects believed that a ball, upon leaving a curved tube, would continue along the same curved path (see Figure 2), a belief indicative of impetus theories.

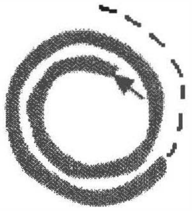


Figure 2. Naïve theories of motion lead to inaccurate predictions of a ball's behavior upon exiting a curved tube. (McCloskey, 1984, p. 289)

In their paper, "Using computer software in teaching mechanics," Graham and Rowlands (2000) discuss several examples of how the world appears contrary to the basic laws taught in physics. Due to this contrary appearance, students entering an introductory physics class have many well-substantiated *misconceptions* about these basics laws. For example, two balls of unequal mass do not hit the ground at the same time when dropped from a tower, and a hockey puck when slid across ice does not continue in constant motion forever. These apparent *misconceptions* are not misconceptions at all. They are easily proven facts about the behavior of objects in our world. As discussed by Graham and Rowland (2000), the difficulty in teaching the basic laws of Newtonian physics is that they are “augmented by the experience of the physical world as behaving differently” (p. 481).

As discussed, the interaction with a world dominated by the effects of friction and gravity often results in one making inaccurate assumptions regarding the basic laws of Newtonian physics. If, in accordance with mental model theory, these inaccurate assumptions are used in the construction of a mental model, then it and all subsequent predictions and conclusions made from this mental model will be flawed. (Barrouillet & Lecas, 1999). It follows that the development of accurate mental models is a vital component in effective physics education.

Mental Model Accuracy and Conceptual Understanding

Greca and Moreira (2002) in their article, “Mental, Physical, and Mathematical Models in the Teaching and Learning of Physics,” claimed that the first step in understanding a phenomenon or process in physics is to construct an accurate mental model of the theories that explain the phenomenon or process. In order to substantiate their claims, Greca and Moreira conducted research studies on mental models and physics education under the framework of Johnson-Laird’s mental model theory. Their research, carried out with college students taking introductory physics courses at the Federal University of Rio Grande do Sul, Brazil, was designed to investigate the relationship between a student’s development of accurate mental models and his/her ability to solve problems linked to concepts in classical mechanics.

Greca and Moriera (2002) identified several relevant findings in their research that linked the development of accurate mental models and effective physics education. According to their analysis, if a student was not able to construct a mental model for a theory, he/she would rely only on formulas and definitions as the arguments for a particular phenomenon. For these students, the solution to the problem often involved "arbitrary manipulation of formulae as there was not even a linkage between the laws and certain phenomena" (Greca & Moreira, 2002, p. 113). Though this method temporarily supplied adequate answers to a problem, by the end of the term, any equation or definition that was not attached to a mental model had been forgotten. In addition, Greca and Moriera were able to establish that the formation of an accurate mental model lessoned a student's dependence on formulas in the description of a particular phenomenon.

Effectiveness of Traditional Instructional Techniques

In their study, Greca and Moriera (2002) found that the majority of their students were not able to construct lasting mental models that would allow them to formulate scientifically accurate explanations for physical situations, despite their success on evaluations of the corresponding topic. When interviews were conducted at the end of the term, the majority of the students were not able to give accurate explanations for basic physical situations. The inaccurate explanations that were given by their students seemed to be connected to the mental models that the students possessed prior to entering the physics classes. As stated in their article, "one could say that the physics description of the world remained indifferent to the [classroom] experience for the majority of the students" (Greca & Moreira, 2002, p. 112).

Similar difficulties in providing physics instruction with lasting effects on a student's mental models was documented by a team of researchers from the Pennsylvania State University (Tasar, Dana, & Lunetta, 2000). Working under the same structural framework of Johnson-Laird's mental model theory, Tasar, Dana, and Lunetta's research showed that a student would return to his/her initial conception although material that conflicted with this conception had been presented several times. This, in their opinion, suggested that the existing conceptions of an individual serve as a natural tendency or refuge for the individual, and being that it is the most stable form of thinking, they will most often return to it (Tasar, et.al., 2000).

According to mental model theory there is a subtle distinction between encountering inconsistencies and encountering new information. When developing a mental model, we attempt, through reason, to construct a single mental model that satisfies a set of propositions (Girotto, Johnson-Laird, & Legrenzi, 2004). During the reasoning process, if we encounter inconsistencies we may use them to draw further conclusions, but these inconsistencies do not call for one to withdraw a previous conclusion (Girotto, et.al.). According to Girotto, Johnson-Laird, and Legrenzi, the retraction or revision of a conclusion will only occur if one is presented with new information. When new information is contradictory to a previous conclusion, one must retract the conclusion. However, if the original propositions validly imply this conclusion, one must revise, not retract, his/her conclusion. The task of revising this conclusion, and in essence the mental model used to formulate the conclusion, involves attempting to resolve the contradiction.

Both Greca and Moriera (2002) and Tasar, Dana, and Lunetta (2000) concluded that the majority of their students returned to their original mental models after a short period of time. In light of the previous discussions, this suggests that their students were presented with inconsistencies between their *misconceptions* and what is *really* true according to the laws of physics; however, the instructional methods carried out in those situations did not result in lasting changes to their student's mental models. As Girotto, Johnson-Laird, and Legrenzi (2004) concluded, the presentation of inconsistencies alone will not lead to revisions in mental models unless a student can resolve the conflict between the two opposing propositions. Educators are faced with the difficulty of presenting the laws of physics so that students can resolve the conflicts between their current mental models, models that are continually reinforced through the interaction with the world, and the mental models that formal physics instruction attempts to instill.

Currently, there are two main methods of instruction in introductory physics courses, interactive engagement and traditional lecture. Courses that are classified as interactive engagement are designed at least in part to promote conceptual understanding through the interactive engagement of hands-on activities. Courses that are classified as traditional lecture make little to no use of hands-on activities and rely primarily on passive student lectures, recipe labs, and algorithmic-problem exams (Hake, 1998).

Richard Hake (1998), a researcher from Indiana University, conducted a large scale study in which he examined 6,542 students enrolled in introductory physics courses across the country. In this investigation he examined whether the use of interactive engagement methods could increase the effectiveness of introductory mechanics courses beyond the results attained by traditional methods. Over a four year period, Hake completed a survey of pre/post-test results on the Halloun-Hastenes Mechanics Diagnostics test (MD), the Force Concept Inventory test (FCI), and the problem-solving Mechanics Baseline test (MB) which were given in 62 high schools, colleges, and universities on a yearly basis. When comparing courses that were classified as interactive engagement to courses classified as traditional lecture, he concluded that interactive engagement was much more effective at developing a conceptual understanding of introductory physics concepts, as measured by the MD, the FCI, and the MB tests (Hake, 1998). Specifically, Hake found that courses classified as traditional lecture based courses achieved an average gain of 0.23, +/- 0.04. In sharp contrast, interactive engagement courses achieved an average gain of 0.48 +/- 0.14, almost two standard deviations above that of tradition courses (Hake, 1998). As stated by Hake, "the conceptual and problem-solving test results strongly suggest that the use of interactive engagement strategies can increase mechanics-course effectiveness well beyond that obtained with traditional methods" (Hake, 1998, p.74).

Many studies, (e.g., Laws, 1991; Halloun & Hestenes, 1985; Johnson, 2001; Marshall and Dorward, 2000; Russell, Lucas, & McRobbie, 1999; Hoellwarth, Moelter, & Knight, 2005) designed to compare traditional lecture with interactive engagement methods have obtained results similar to those obtained Richard Hake (1998). These studies clearly indicate that interactive engagement, such as a laboratory-based experiment, is a more effective instructional method than traditional lecture for development of a conceptual understanding of introductory physics concepts.

Limitations to Interactive Laboratory-Based Engagement

Although most educational researchers agree on the effectiveness of interactive laboratory-based activities, these activities have limitations. Graham and Rowlands (2000), explain that mechanics is based on what they call idealized abstractions. An idealized abstraction is a hypothetical situation whereby conditions are imposed in order to simplify a concept within mechanics. Frictionless surfaces, gravity-free environments, and a golf range with no air resistance are examples of idealized abstractions. Though these abstractions simplify the problems, they present an environment or situation that cannot be represented physically. Due to this fact, students appear to have tremendous difficulties in developing mental models that incorporate these abstractions (Graham & Rowland, 2000).

Brown and Edelson (1999) also discuss several of the limitations encountered in laboratory-based experiments. Similar to the conclusions of Graham and Rowland (2000), Brown and Edelson claim that there is a wide range of concepts that involve abstract phenomenon that are difficult to replicate in a classroom setting. As a consequence, these concepts become difficult for students to comprehend. Brown and

Edelson go on to discuss that many classroom laboratory experiments simplify and de-contextualize scientific phenomenon to the point that novices fail to see their connections to real-world events outside the classroom. McCloskey (1984), in his discussion of naïve impetus theory, also pointed out that students fail to apply scientific knowledge to everyday events.

Computer Simulations – An Alternative Instructional Technique

If laboratory investigations fail to provide adequate evidence to support the development of an accurate mental model of a scientific theory, another method of presentation must be called upon. Many researchers believe that computer-based simulations have the ability to compensate for the shortcomings of laboratory-based experiments. Over the past two decades, the excitement surrounding the possibility of computer simulations within physics education has steadily grown. Despite this excitement, a tremendous amount of debate also surrounds their use. This debate is in regards to the actual effectiveness of computer simulations at fostering long term changes to a student's mental models.

Several studies have claimed that the use of computer simulations within a physics classroom is effective at fostering changes in mental models. Tao and Gunstone (1999), in their article "Conceptual Changes in Science through Collaborative Learning at a Computer," investigated whether and how collaborative learning at a computer fosters conceptual change. In their investigation, a suite of computer programs were developed to confront students' alternative conceptions in mechanics by presenting them with discrepant events. These programs were integrated into a high school introductory physics class. By collecting data in the form of pre-, post-, and delayed post-tests, they showed that computer-supported collaborative learning provided students with the opportunities to construct shared understanding which led to conceptual changes for many of the participating students. Tao and Gunstone's results also showed that at the time of the delayed post-test, many of the students had regressed to their previous conceptions. In support of the findings discussed earlier by Girotto, Johnson-Laird, and Legrenzi (2004), Tao and Gunstone suggested that a student needed to personally make sense of the new understanding, and when he/she did not, his/her conceptual change was short-lived.

James M. Monaghan from California State University, and John Clement of the University of Massachusetts (1999), conducted interviews with three high school post-physics students to determine if interaction with a relative motion computer simulation could improve relative motion understanding. Sub-questions of their study included whether the students could transfer what they learned online, during the interaction with the computer simulation to off-line situations, with particular focus on the simulations ability to facilitate mental simulations off-line (Monaghan & Clement, 1999). It is important to note that Monaghan and Clement's (1999) use of the term mental simulation is not synonymous with Johnson-Laird's term mental model. However, as discussed by Monaghan and Clement (1999), the ability to create an accurate mental simulation is indicative of an accurate knowledge schema, a term that can be used synonymously with Johnson-Laird's mental model. More general purposes of their study were to examine helpful or detrimental modes of thinking that may occur during computer simulation use, and to identify any "hidden pitfalls" (Monaghan & Clement, 1999, p. 921) associated with computer simulation use.

Upon careful analysis of the pre-test and post-test scores as well as the interviews conducted with the students, Monaghan and Clement (1999) concluded that for two of the students, visualization of the post-test problems was facilitated by memory of the computer simulations. This visualization guided the students to accurate problem solutions and showed that transference occurred between the computer simulation and the off-line post-test problems. The ability of students to solve problems off-line indicated that computer simulations foster the development of appropriate mental simulations of target problems (Monaghan & Clement, 1999). There was also evidence that the skills obtained during the computer simulation intervention were dynamic and allowed the students to draw appropriate analogies in new situations to make inferences regarding the outcome of those situations (Monaghan & Clement,1999).

Despite the success of these two students following the use of the computer simulations, results obtained from one of the students in Monaghan and Clement's (1999) intervention program indicates that the use of computer simulations is not a cure-all for alleviating the difficulties that students have with abstract physics concepts such as relative motion. These particular results indicate that students may actually regress following the use of a computer simulation. Monaghan and Clement (1999) hypothesized that regression may be a consequence if a student does not understand the computer simulation, if the student inaccurately transfers knowledge gained from the computer simulations to analogous situations that are not truly analogous, or if the student visualizes scenarios that are not scientifically accurate.

In 2000, Clement and Monaghan published another research study entitled "Algorithms, Visualization, and Mental Models: High School Students' Interactions with a Relative Motion Simulation." In this study they investigated the use of computer simulations a means of reversing the difficulties that people have in understanding relative motion concepts. They hypothesized that the "construction of visual models [via computer simulations], the resolution of these visual models with numeric models, and in many cases the rejection of commitments such as the belief in one 'true' velocity, are necessary for students to form integrated mental models of relative motion events" (Clement & Monaghan, 2000, p. 311). To investigate their beliefs, thirty-eight high school science students were separated into two groups. One group received algorithmic instruction of relative motion and the other group performed predict-observe-explain activities with relative motion computer simulations. Although both groups posted significant gains on the relative motion diagnostic test, analysis of the interviews showed striking differences between the problem solving approaches used by the two groups. Students that received algorithmic instruction tended to "mechanically solve exercises without reflection" (Clement & Monaghan, 2000, p. 323). Instruction via computer simulations however, "appeared to be far less susceptible to facilitating mechanical solution of problems" (Clement & Monaghan, 2000, p. 323). Monaghan and Clement describe evidence that the cognitive dissonance generated by the computer simulations appears to cause changes in a students mental model of an event, and potentially his/her mental model concerning the relativity of reference frames.

The results obtained by Monaghan and Clement (1999) showed that computer simulations cannot be seen as a panacea for the difficulties that students encounter when studying abstract concepts related to physics. However, their research had many implications regarding use of computer simulations as to tool for aiding in the development of accurate mental models in area of Newtonian physics (Monaghan & Clement, 1999, 2000).

Carmen Pena, from the University of Houston, and Stephen Alessi, from the University of Iowa (1999), conducted a large-scale study that also found evidence that pointed to the effectiveness of using computer simulations within a physics classroom. The study, which involved 330 students, compared hands-on laboratory experiments with computer simulations. In the hands-on laboratory experiments, a group of students was asked to investigate the motion of a falling object using a picket fence and a photogate. Another group of students was asked to interact with a simulated version of this hands-on investigation. Both groups completed a pretest and posttest which assessed their understandings of the presented concepts as well as their confidence levels regarding their answers to the content questions. Analysis of the pre- and post-tests showed no significant differences between the students in the hands-on condition and the students in the simulation condition. This suggests that both methods "facilitated the comprehension of the concepts involving the behavior of objects in freefall" (Pena & Alessi, 1999, p. 454). Pena and Alessi hypothesized that since "the simulation investigations eliminated much of the logistical overhead" (p. 455) associated with the in-depth laboratory investigations, more teachers would be willing to incorporate these investigations within their courses.

Many researchers have discussed the general benefits regarding the use of computer simulations within a physics classroom. Zacharia (2005) published a study in the *International Journal of Science Education* that described the results of his study which compared the effects of interactive computer simulations with science textbook assignments on the nature and quality of a subject's explanations regarding physical phenomenon in mechanics, waves/optics, and thermal physics. The results indicated that use of computer simulations had more positive impact on the nature and quality of the subject's explanation. The explanations were more elaborate, reflected cause-effect reasoning, and formal reasoning (Zacharia, 2005). McDonnell, McAtamney, Keegan, and McMahon (2001), in their article "Aspects of Virtual Reality and Visualization," which appeared in the *International Journal of Modern Physics*, state that "understanding is helped if you can have some sort of picture in your head" (p. 581). They claim that multimedia tools are mechanisms for instilling this picture. Tao (2004) discussed the mediating role that the computer simulation played while students, working in dyads, investigated image formation by lenses. The results of this study showed "that overall, students improved their understanding of image formation" (Tao, 2004, p. 1171). In a similar study, Eylon, Ronen and Ganiel (1996) showed that RAY, a computer based learning environment developed as a tool for enhancing the learning of geometric optics, contributed significantly to student understandings of geometric optics. Tao and Gunstone (1999) explained that computer simulations allow students to freely explore the micro-world of the program by changing the parameters of the variables and immediately visualizing the consequences of their manipulations. He claimed that this allowed students to interpret the underlying scientific conceptions of the program and to compare them with their own conceptions. Graham and Rowlands (2000), in their article "Using Computer Software in the Teaching of Mechanics," reasoned that the major difficulty in challenging inaccurate mental models of mechanics is the inability to set up an experiment in which the student or teacher is able to control all of the variables. They conclude that many of these difficulties can be removed through the use of software that can simulate many different physical situations.

Limitations to Computer Simulations

Despite the many benefits that computer simulations provide for physics education, as with any instructional method, there are limitations and negative consequences involved in their use. Steinberg (2000), from the City College of New York, examined two different instruction techniques used in an introductory physics course to present the effects of air resistance on the motion of an object. One instructional technique involved the use of a computer-based tutorial, and the other used exclusively non-computer-based techniques. Steinberg observed that in both situations the students were diligent and engaged, however, since the students without a computer had no way of directly verifying their answers, they spent more time reasoning about the logic behind their answers. In contrast, students who had access to the computers would rely on receiving the answers from the computer without taking the opportunity to substantiate their answers for themselves. The students seemed to adopt the attitude of “it is true because the computer says it is true” (Steinberg, 2000, p. S39). From his observations, Steinberg (2000) claimed that “there is a danger that with computer simulations, students will see no need to take responsibility for their own understanding” (p. S39).

A Lab of a Different Nature – Computer Simulations with Traditional Labs

Since laboratory investigations and computer simulations both have clear advantages to physics instructions, some researchers have concluded that the two pedagogical methods should be implemented in conjunction with each other. In her article, “Integrating the study of trigonometry, vectors, and force through modeling,” Helen M. Doerr (1996), of Syracuse University, discusses the benefits of using computer simulations in conjunction with laboratory based experiments to construct an understanding of the motion of an object down an inclined plane. The study was conducted in an integrated algebra, trigonometry, and physics class containing seventeen students ranging from grade nine to grade twelve. Doerr collected data in the form of interviews, observations, pretests, and posttests. A clear benefit described in her research was that when the students’ analyses of their experimental results were inconclusive, they turned to the simulation environment in an information-gathering approach in order to construct a complete understanding. Another benefit was that the simulation environment allowed the students to set up experiments that were free of experimental error. The simulated experiments also allowed the students to run many more trials, and resulted in the refinement of the conclusions generated during the hands-on experiment. Doerr concluded that in beginning an experiment with a hands-on activity, the students generated their own representations of the phenomenon. They could then verify their representations through the simulation.

"In principle, the simulations should serve as a cognitive framework for enhancing the subsequent more open-ended inquiry learning in the subject matter domain of the experiments" (Zacharius & Anderson, 2003, p. 618). To test their opinion, Zacharia and Anderson integrated simulations and experiments into a one-semester physics class. The results from semi-structured interviews with the participating students indicated that the use of computer simulations prior to the completion of an inquiry-based experiment improved the student's ability to make acceptable predictions and explanations of the phenomenon in the experiments. From the interviews, they were also able to conclude that the students experienced significant changes in their mental models related to the areas of mechanics, waves/optics, and thermal physics.

The research shows that students typically enter introductory physics classes with incredibly naïve theories of motion (McCloskey, 1984) that are deeply rooted in their current mental models. It is the goal of physics education to present students with the inconsistencies that exist between their current mental models and *truth* according to the laws of physics. The exact pedagogical methods for this presentation are not universally agreed upon. However, what is obvious to most researchers is that if integrated properly, computer simulations can enhance the learning that takes place within a physics classroom. As stated by Steinberg (2000), “if we ignore the critical role of computers in science and engineering, we would be doing a disservice to students” (p. S40).

Chapter 3: Applications and Evaluation

Objective of the Study

As stated previously, the main goal of this action research project is to determine if a computer simulation can act as a bridge between scientific theory and perceived reality. If a computer simulation is effective at bridging this gap, students should be able to more effectively revise their naïve theories of motion. The topic of focus for this project was Newton's First Law of Motion. The law states, "An object that is at rest will remain at rest, and an object that is moving will continue to move in a straight line with constant speed, if and only if the net force acting on that object is zero" (Zitzewitz, 2005, p. 94). Although this law can be recited by most students by the time they reach high school, I have found that few students accurately apply this law to the motion of everyday objects.

Participants in the Study

In order to investigate these questions, an action research project was developed within the context of a high school physics classroom. Thirty-six eleventh and twelfth grade students, divided between three classes, participated in the project. Of the thirty-six students, three students are classified as "special needs" students with instructional modifications authorized through a New York State 504 or IEP. The group contained seventeen girls and nineteen boys, with ethnic origins being predominately white/Anglo-Saxon. According to the New York State School Report Card, the high school contains approximately 850 students with a demographic breakdown of 85% white (not Hispanic), 7% black (not Hispanic), 6.5% Hispanic, and 1.5 % American Indian, Pacific Islander, or Asian. The high school is officially classified by the U.S. Department of Education as a low-income school district, with 15% of the student population eligible for the free school lunch program.

The classroom contains twenty student desks located at the front of the room and three large laboratory tables located in the back of the room. A computer cart containing fourteen laptops is located in the classroom. Each laptop has wireless internet capabilities and the Interactive Physics ® software package. An InFocus ® computer video projector is available to the teacher for large group instruction.

Classroom instruction takes place in the form of lectures and laboratory activities. Formal lectures are presented five times a week during forty-minute periods. Laboratory instruction occurs three times a week during a forty-minute period that immediately follows the lecture period. The back-to-back lecture and lab periods allow instructional flexibility for activities that may require more than a forty minute period to complete. The classroom teacher, author of this paper, is certified by New York State in the area of Physics 7-12 and has five years teaching experience within the New York State educational system.

Procedures of the Study

Using Newton's First Law as a basis for the action research project, I developed a laboratory investigation in which a computer simulation was used in conjunction with a hands-on laboratory activity. This hands-on laboratory activity involved the exploration of the effects of balanced and unbalanced forces on the motion of a dynamic cart. Using the Interactive Physics ® software, I designed a computer simulation that mirrored the hands-on activity. After a short description of the activity, students worked in dyads to complete the laboratory investigation.

Three separate classes, containing a total of 36 students, completed the laboratory investigation. Each class had an 80-minute time block to complete the tasks. The main objective in the investigation was to determine how balanced and unbalanced forces affect an object's motion. Within the hands-on setup (see Figure 3), there appears to be only two forces acting on the cart, the "engine force" and the "resistance force," however, there are other horizontal forces that affect the motion of the cart. These forces include the frictional forces present as a consequence of air resistance and surface to surface contact.

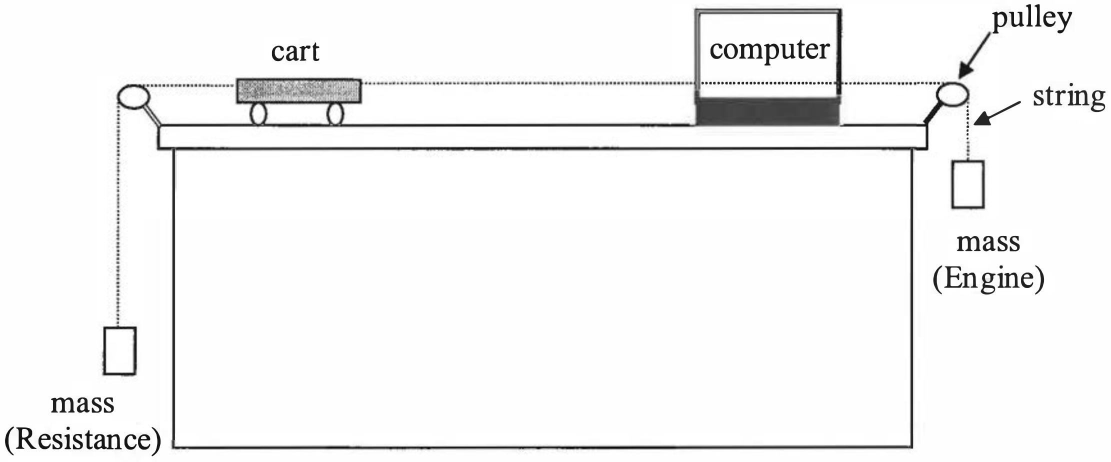
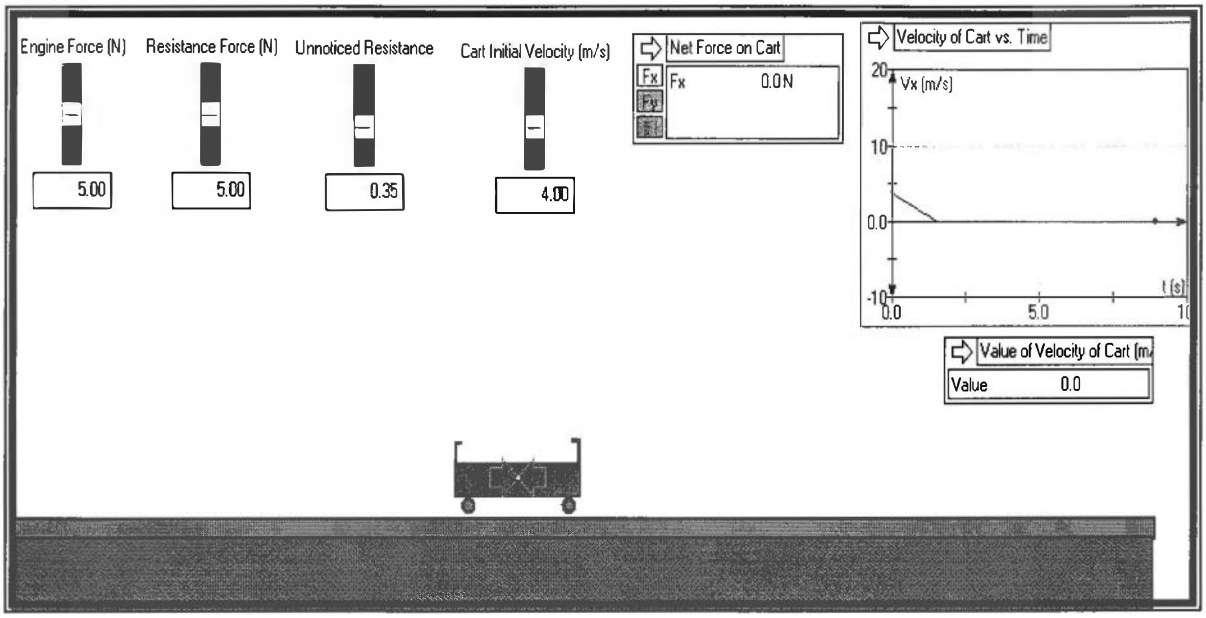


Figure 3. Hands-on setup for each group of students.

Within the Interactive Physics ® computer simulation (see Figure 4) the students had the ability to control all of the forces that were affecting the motion of the cart as well as the initial velocity of the cart. The students were able to control these variables using the four sliders labeled Engine Force, Resistance Force, Unnoticed Forces, and Initial Velocity. Graphs and meters within the simulation allowed the students to quantitatively and qualitatively analyze the motion of the cart. During the investigation, specific emphasis was placed on the type of motion possible when all forces were in equilibrium. Through careful experimentation and observation the students were able to observe situations resulting in either accelerated motion or constant velocity motion.



Engine Force (N) 5.00

Resistance Force (N) 5.00

Unnoticed Resistance 0.35

Cart Initial Velocity (m/s) 4.00

Net Force on Cart
Fx 0.0 N

Value of Velocity of Cart (m/
Value 0.0

Figure 4. Interactive Physics computer simulation interface.

Instruments of the Study

Qualitative and quantitative data were collected throughout the course of the investigation. Prior to any intervention, each student was asked to complete a pretest designed to identify the presence of any naïve theories motion relating to Newton's First Law of motion (see Appendix B). Qualitative and quantitative data were gathered from the pretests. Upon completion of the pretest, several students took part in short interviews related to their responses to the pretest questions (see Appendix C). The following hour was devoted to the completion of the laboratory investigation (see Appendix D). Twenty-four hours later, each student was asked to complete a posttest (see Appendix E). This posttest was designed to identify any changes in mental models of motion that resulted from the investigation. Post-intervention interviews (see Appendix G) were then conducted with the students that took part in the pre-intervention interviews. Finally, each student completed a questionnaire that explored his/her opinions on the effectiveness of using computer simulations in conjunction with hands-on activities (see Appendix F).

Chapter 4: Results

Pretest

Greca and Moreira (2002), McClosekey (1984), and Tasar, Dana, and Lunetta (2000) independently concluded that it is very difficult to provide physics instruction with lasting effects on a student's mental models. As stated by Greca and Moreira (2002), "one could say that the physics description of the world remained indifferent to the [classroom] experience for the majority of the students" (p. 112). According to Johnson Laird's Mental Model Theory this difficulty arises as a consequence of a student's inability to construct a single mental model that satisfies a set of propositions. The propositions in this case include truth according to reality and truth according to theory. If a student is unable to resolve the conflict between these two truths, the student's mental model of motion will remain unchanged.

The first step in my research was to determine if the regular classroom instruction received by my students had been sufficient to eliminate any of their naïve mental models of motion (see Appendix A). In order to make this determination, a pretest was given to each of the 36 students prior to any intervention. Despite success on written tests given previously in the semester, quantitative analysis of the pretests showed that 60% of the students predicted that a car initially traveling at 65 mph would come to a stop if the resistance force was equal and opposite to the engine force. During interviews sessions, three students were asked to explain why they believed the car would stop.

Student A1 commented:

> It is about equal and opposite forces [Newton's Third Law], like if you ran into a wall. It pushes back on you with an equal and opposite force. This force results in no motion.

Student A2 commented:

> It is what happens in everyday life. If something pushes against you with an equal force it will cause you to stop.

Student A3 commented:

> The car's motion would have to stop; it would be at rest. The force propelling it and resisting it would cancel out and with no net force acting on it, it would not move.

Each explanation, as well as the predictions made by 60% of the students, violates Newton's First Law of motion and points toward the retention of a naïve theory of motion. It was obvious that for the majority of the students, regular classroom instruction was not effective at causing lasting changes to their mental models.

Laboratory Investigation

Working in dyads, the students completed the laboratory investigation described in the *Procedures of the Study* section of this report. The investigation allowed the students to interact with both a computer simulation and hands-on equipment to investigate the behavior of an object under situations involving balanced and unbalanced forces.

While the students were completing the investigation, I made several observations regarding their use of the provided equipment. I noticed that the students seemed to prefer to manipulate the variables within the computer simulation instead of the hands-on equipment. When I inquired about my observation one student commented, “The computer simulation is easier to control, therefore it is more reliable.” Despite the students’ preference to manipulate the computer simulation, there seemed to be a hesitation by the majority of the students to trust the results of the simulation. The students often returned to the hands-on equipment to verify the results obtained through the use of the computer simulation. As stated by a student working with the computer simulation, “The computer helps me to understand, but it does not prove anything to me. For that I need the cart in front of me.” All of the students seemed to enjoy and benefit from the simultaneous use of computer simulation and the hands-on equipment.

Posttest

The posttest, which was identical to the pretest, was given 24-hours after the intervention. The time lag between the intervention and the posttest was designed to assess whether the intervention had lasting effects on the mental models of the students.

Analysis of the posttest responses showed an increase in the percentage of correct explanations for the car scenario. Compared to the 60% accuracy on the pretest, 92% of the participating students correctly explained that the car would continue at a constant velocity when the sum of the resistance forces was equal and opposite of the engine force. On the posttest, the students were asked to describe how they arrived at their explanation for the behavior of the car. In answering this question, 19 students identified the computer simulation as the main source of assistance in the development of their explanation. Written comments to this question included:

> By using the computer simulation there is a visual to back up the theories that have been proven to be true.
>
> The graphs within the computer simulations allowed us to understand what truly happens when all of the forces were taken into consideration.
>
> At first I thought that car would stop if the resistance forces were equal to the force of the engine, but after doing the experiment on the computer I see that the car kept moving as long as the unnoticed forces were at zero.

Post-intervention interviews were conducted with the three students who participated in the pre-intervention interviews. In the pretest all three students incorrectly predicted that the car would stop. In the posttest all three students correctly predicted that the car would continue to move at a constant velocity. During the post-intervention interview the three students were asked to explain how they came to conclude that the car would remain in constant velocity motion. Their responses included:

Student A1:

> When the net force is zero, there's nothing to stop the car. So, if it was moving it would keep moving, but not change in speed.

Student A2:

> I was initially thinking of what would happen on earth, not in the physics ideal world. I saw in the computer simulation and in the hands-on activity that if the net force is zero, a car already moving would not stop.

Student A3:

> In both the computer and in real-life, when we added enough mass to create a truly balanced system, the car kept moving at a constant speed after you gave it a push [an initial velocity].

There are many factors that could have contributed to the increase in the percentage of correct explanations of the car scenario, however, the results from both the posttests and the interviews point toward students making accurate revisions to their naïve mental models of motion through the simultaneous use of the computer simulation and the hands-on activities. However, the comments made by Student A2 during the post-intervention interview may be a cause for concern about student beliefs. It is possible that a portion of the students see a major disconnect between what "happens on earth" and what happens "in the physics ideal world." In her comments she still seems to be struggling with bridging the gap between theory and reality. Despite her ability to correctly predict the behavior of the car, it appears as though the intervention may not have been helpful in revising her naïve theories of motion.

Post Intervention Questionnaire

Once the students finished all of the components in the intervention, they were asked to complete a post-intervention questionnaire. The questionnaire was designed to collect their opinions regarding the effectiveness of a computer simulation when used in conjunction with a hands-on laboratory investigation.

The questionnaire asked the students to comment on whether the computer simulation was effective at clarifying the results of the laboratory investigation. According to their responses, 92% of the students believed that the computer simulation was effective. The three students, 8% of the population, which said that it was not effective, explained that regular classroom instruction was sufficient for them to understand the concept. For the students that supported the use of the computer simulation, comments included:

> It [the computer simulation] shows us exactly what teachers try to put into words.
>
> The computer simulation was a visual example that worked the way that theory says it should.
>
> It [the computer simulation] helped me to see what was actually taking place, which clarified my misconceptions.
>
> Sometimes in physics it is hard to completely understand some of the theories, like how a car could stay in motion even if the force of

> friction was equal to the engine force. The computer simulation actually showed me how this is true.
>
> The computer helped give a clear picture in my mind of how resistance affects motion.
>
> By interacting with the computer, and changing the resistance for myself, it was a lot easier to visualize what happens, rather than just discussing it in class and trying to create my own mental picture.

I was also curious if the students believed that the computer simulation contributed to their understanding of the physics concept beyond what they would have understood with only the hands-on laboratory activity. From the results of the questionnaire, 86% of the students believed that the computer simulation did extend their understanding. Aligned with the results from the first question, the students who indicated that the computer simulation did not extend their understanding explained that they already had a clear understanding of the concept. The students who indicated that the computer simulation extended their understanding explained:

> The mixture of real-world lab with the computer simulation of ideal conditions, gave me a more complete understanding of the law as well as a real world application.
>
> No matter how hard we tried, we could not 'even' the friction with the added mass. Real-life just can't be perfect, so you always end up with results that are aligned with theory. In the computer simulation, your experiment can be perfect.

> The hands on activity helped a lot, but the computer simulation proved the concept better by showing the graphs that kept on going.
>
> The physics concept is based on things that can't be proven solely in a lab experiment done in a classroom. It takes further understanding to believe something that goes against what you see everyday.
>
> The simulation helps to put a real-life perspective on theoretical situations.

Finally, I was curious about the students' opinions regarding the use of computer simulations in conjunction with labs completed earlier in the semester. When asked to comment on this topic, the same 86% of the students felt as though a computer simulation would have aided in their understanding in several laboratory investigations. Student comments included:

> During some of the labs, I would be doing it wrong and not know why. With a computer simulation you can see how it is supposed to be and then work towards making your lab close to that.
>
> I think computer simulations give very clear examples of concepts in physics. Some labs like the one on waves might have been clearer if I could have seen the concepts happening on the computer.
>
> There are a lot of labs where we had to imagine certain conditions that had a direct effect on our results. By having to imagine it, you don't really get a complete grasp of the concept. Perhaps if we had the

> computer simulation for such labs, we would have been able to visualize the concept a little more effectively.

The comments from the majority of the students showed tremendous support for the simultaneous use of computer simulation and hands-on laboratory investigations. Any comments that did not support the use of computer simulations were from students that felt as though they had a sufficient understanding of the concepts without the extra assistance.

Chapter 5: Conclusions and Recommendations

Discussion

The analysis of the posttests, interviews, and questionnaires reveals two major themes. As the posttest results and the post-intervention interviews show, the students appear to be making accurate revisions to their naïve mental models of motion, as related to Newton's First Law of Motion. As noted by one student, "At first I thought that car would stop if the resistance forces were equal to the force of the engine, but after doing the experiment on the computer I see that the car kept moving as long as the unnoticed forces were at zero."

The second major theme, evident on the student questionnaires, is that the majority of the students believe that the computer simulations assisted in the clarification of the laboratory results and allowed them to more fully understand the theoretical concepts being presented in the laboratory investigation. Typical student comments were similar to that of this student, who said, "The mixture of real-world lab with the computer simulation of ideal conditions gave me a more complete understanding of the law as well as a real world application."

Overall, computer simulations, when used in conjunction with traditional laboratory-based experiments, allow my students to bridge the gap between theoretical truths and perceived truths. As one student commented, "Looking at the motion of the car through the computer simulation helped me to make the connection from the lab to the physics theory of motion."

Action Plan

Based on the themes that have emerged in this action research project, I plan to develop more laboratory investigations which contain computer simulations and traditional hands-on activities. Many of these simulations can be developed through the Interactive Physics ® software. However, the use of this particular software is limited mostly to concepts in mechanics. The simulations necessary for investigations within other areas of physics, such as optics, waves, electricity and magnetism, and modern physics, will need to be found on the internet or purchased through a vendor. There are many simulation bundles available for purchase through any physics education catalog. For simulations in modern physics, optics, and waves, NeoSci® makes three popular simulation software bundles, NeoSci ® Modern Physics Simulation, NeoSci ® Light & Optics Simulation, and NeoSci ® Waves & Sound Simulation. For simulations in the areas of electricity and magnetism, Discovery School® has several software bundles available.

Software purchases will need to be approved by the technology committee within our high school. Submission and approval of technology purchases would need to be completed by July 1, 2006 to assure time for installation and trouble shooting. Any laboratory activities designed to include the new software would be written throughout the course of the 2006 – 2007 school year. Data regarding the effectiveness of this software would need to be collected throughout the course of the first year of implementation.

The results of this action research process will be shared at two levels. First, the research will be shared on a local level within science department meetings. If I obtain approval for the software purchases, many of the simulations would be appropriate for use within other science disciplines. Training sessions would need to be organized and made available to any teachers desiring to use the simulation software. Upon approval from the superintendent of curriculum, in-service credit could be awarded to any participating teachers. The results of this action research project should also be shared with other physics teachers in the surrounding school districts. A forum for sharing is possible through the RAPTOR organization. RAPTOR, Rochester Area Physics Teachers Out-Reach, is a group of local physics teachers who convene once a month to share ideas and discuss issues related to physics education. I hope to give a short presentation on the use of computer simulations in conjunction with traditional laboratory investigations during an upcoming meeting.

Recommendations for Future Research

This research has indicated that the use of computer simulations in conjunction with laboratory-based experiments helped students to revise their naïve mental models of motion. However, very little research as been done to identify other areas in physics where this instructional technique would help to increase student understanding. Future researchers should focus on identifying the role of computer simulations in areas such as Electromagnetism, Optics, and Modern Physics. Once this role is identified, resources should be allocated on a national, state, and local level for the creation of a physics curriculum that utilizes computer simulations within a physics laboratory setting.

Conclusions

On the basis of their everyday experiences, people develop remarkably well-articulated naïve theories of motion (McCloskey, 1984). These naïve theories of motion are constructed through interaction with a world dominated by latent forces. The presence of these forces is so universal that their effects are considered to be a normal part of the behavior of an object in motion. As a consequence, the mental models that a person develops when interacting with this world are inherently flawed. These flawed mental models result in a gap between theory and perceived reality. Physics educators are faced with the difficult task of eliminating this gap. Based on the results of this research project, computer simulations may act as a bridge between theory and perceived reality when used alongside traditional laboratory investigations. As one of my students commented, "Looking at the motion of the car through the computer simulation helped me to make the connection from the lab to the physics theory of motion."

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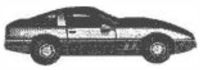
Appendix A

Student Pretest

Question One

A, B, and C below show a car in three different scenarios of motion.

A

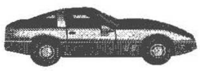


At rest
v = 0 mph

B

Constant Velocity
v = 65 mph

C



Speeding up
v = 50 mph increased to 65mph

Classify each scenario as having either a net force of zero or a net force greater than zero. (Net force of zero means that all of the forces balance each other out. A net force greater than zero means that there is an unbalanced force present.) For each car, explain why the classification must be true.

Car A:

Car B:

Car C:

Question Two

A car is traveling down the road at 65 mph. If the resistance forces (air, friction, etc.) gradually increased until they were pushing against the car with a force that is equal and opposite to the force of the engine, what would happen to the car's motion? Explain your answer.

Describe how you arrived at the explanation for Question Two. What allowed you to answer the question?

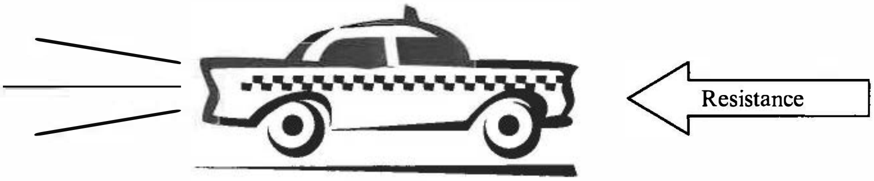
Appendix B

Pre-Intervention Interview Session

To the Participant:

All information in this interview will remain confidential. Your opinions will be used to draw general conclusions regarding the effectiveness of computer simulations used in conjunction with traditional laboratory experiments in the development of accurate mental models.

A car is traveling down the road at 65 mph, if the resistance (air, friction, etc.) was pushing against the car with a force that is equal to the force of the engine, what would happen to the car's motion?



Describe why you believe this.

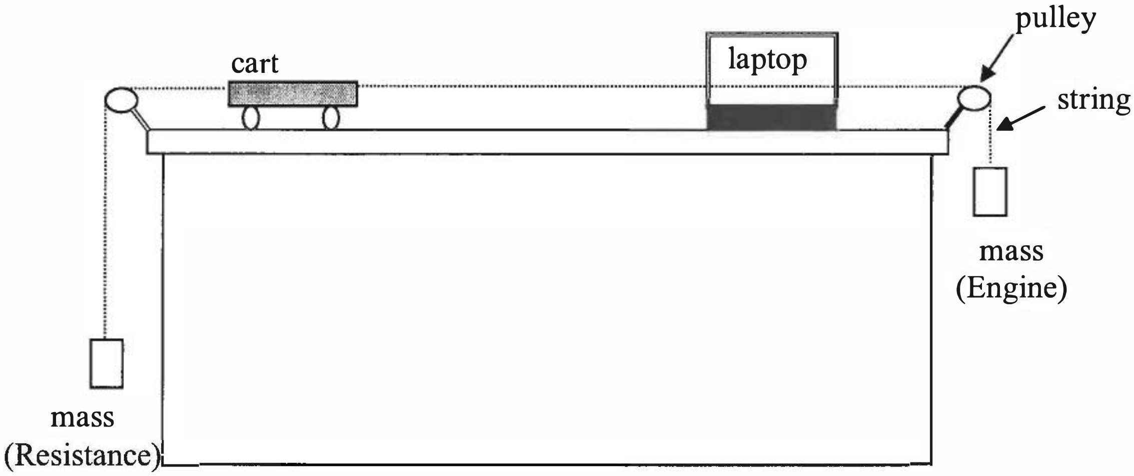
Appendix C

Laboratory Investigation

Problem: How do balanced and unbalanced forces affect an object's motion?

Our personal theories of motion are constructed through interaction with a world dominated by the effects of friction and gravity. The presence of these forces is so universal that their effects are considered a normal part of the behavior of an object in motion. Consequently, our personal theories are inherently flawed. Let us look at a simple example, a car traveling down the road. If the resistance forces, such as friction and air resistance, are exactly equal and opposite to the car's engine force, will it stop?

Lab Set –up:



Set-up

1. Set-up the equipment as shown above.
2. The Interactive Physics simulation can be opened from the student shared folder on the network drive. Open the IP Models folder.

Procedure:

1. Hang two 100 g masses from each string as shown in the diagram above. The force pulling to your right will represent the engine force and the string pulling to your left will represent the resistance force. (If these forces are equal and opposite, will the cart stop?)

2. Give the cart a gentle push to the right. Describe the carts behavior. _______
   ____
   ____

3. The forces that we can clearly see are equal and opposite, however, there are unnoticed forces that are causing the visible forces to be unbalanced.

4. Look at the computer simulation. Set the following parameters:

   Engine Force = 5 N
   Resistance Force = 5 N
   Unnoticed Resistance = 0.10
   Initial Velocity = 4.0 m/s

   Click Run. Describe what happens to the cart. ______________________

   ____

5. Keeping everything else the same, adjust the Unnoticed Resistance to zero. Click Run. Describe what happens to the cart. Pay close attention to the graph. ______________________

   ____

   ____

6. If the resistance force was exactly equal and opposite to the engine force, would a car in motion stop? ______________________

   ____

   ____

7. The difficulty in laboratory investigations is trying to control the forces that we can't see. To attempt balance out the unnoticed resistance force small masses and/or paper clips from the engine mass end until you can get your cart to roll at a constant velocity across the counter. (You will have to tap the cart to get it to start moving after each adjustment is made.) Once this is accomplished you have truly created a system where the resistance force equals the engine force (a net force of zero).

8. From the network folder open the "Corvette Simulation." This simulation is designed to exactly match reality. You can control the engine force, but the resistance force is out of your control. As the car speeds up, the resistance force increases due to an increase in air drag. As the resistance force increases, the net force approaches zero (as indicated in the meter). When the net force is equal to zero (in other words, the resistance force is exactly equal and opposite to the engine force), what happens to the velocity of the car?

   ____

   ____

   ____

Conclusion:

If the resistance forces, such as friction and air resistance, are exactly equal and opposite to the car's engine force, will the car stop? ______________________________

____

____

____

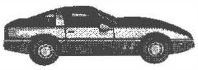
Appendix D

Student Posttest

Question One

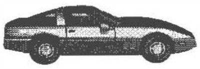
A, B, and C below show a car in three different scenarios of motion.

A



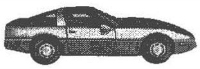
At rest
v = 0 mph

B



Constant Velocity
v = 65 mph

C



Speeding up
v = 50 mph increased to 65mph

Classify each scenario as having either a net force of zero or a net force greater than zero. (Net force of zero means that all of the forces balance each other out. A net force greater than zero means that there is an unbalanced force present.) For each car, explain why the classification must be true.

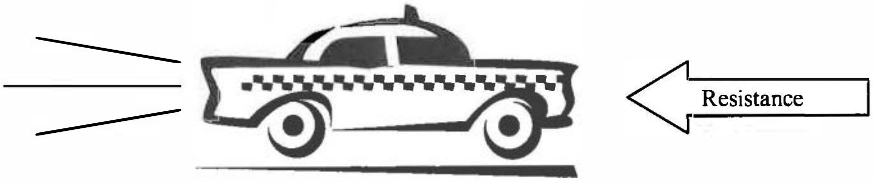
Car A:

Car B:

Car C:

Question Two

A car is traveling down the road at 65 mph. If the resistance forces (air, friction, etc.) gradually increased until they were pushing against the car with a force that is equal and opposite to the force of the engine, what would happen to the car's motion? Explain your answer.



Describe how you arrived at the explanation for Question Two. What allowed you to answer the question?

Appendix E

Post-Intervention Questionnaire

To the Participant,

All information in this questionnaire will remain confidential. Your opinions will be used to draw general conclusions regarding the effectiveness of the computer simulations used in conjunction with traditional laboratory experiments in the development of accurate mental models.

1. Did the computer simulation clarify the results of the laboratory investigation?

   No Yes

   Explain how or why.

2. In your opinion, did the computer simulation contribute to your understanding of the physics concept beyond what you would have understood with only the hands on activity?

   No Yes

   Explain how or why.

3. Thinking back to other labs that we have done in physics this year, do you think a computer simulation of the investigation would have aided in your understanding of the lab and the concept it was trying to teach?

   No Yes

   Explain why.

4. Rate the effectiveness of the computer simulation in helping you to develop a mental picture of the physics phenomenon.

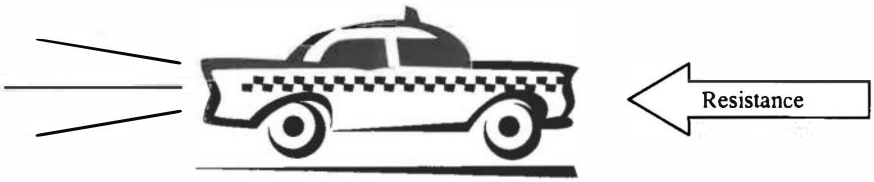
1	2	3	4	5
Not Effective				Very Effective

Appendix F

To the Participant:

All information in this interview will remain confidential. Your opinions will be used to draw general conclusions regarding the effectiveness of the computer simulations used in conjunction with traditional laboratory experiments in the development of accurate mental models.

A car is traveling down the road at 65 mph. If the resistance (air, friction, etc.) was pushing against the car with a force that is equal to the force of the engine, what would happen to the car's motion?



Describe why you believe this.