

Physics Education Through Demonstrations and Personal Interaction

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Abstract:

The purpose of this thesis is to study the implementation of various learning tools to help a general audience understand basic physics concepts. The basis of this work lies in the development of demonstration-based seminars, which relate physical concepts to everyday ideas and experiences. Through the use of entrance and exit surveys, the levels of understanding of those in attendance were gauged. The results indicate that in all of the seminars there was a significant improvement in understanding, suggesting that the concepts were being conveyed in a meaningful manner.

I. Introduction:

If senior research is meant to focus on problems at the frontier of the physics world, then no project can be more appropriate than one focusing on physics education. It is my goal to stimulate student interest in physics, with the hope that more students may decide to study the subject matter in-depth, but with the immediate impact of a better understanding of some of the fundamental ideas of the science.

With the technology boom of the late 20th Century, a solid education in the sciences has become an invaluable asset. Unfortunately, American students are showing less interest and demonstrating less knowledge in the sciences today than they did four years ago. According to a report released November 21 by the National Assessment of Educational Progress Ref. [1], as printed by the Washington Post, more than 80 percent of the nation's high school seniors lack proficiency in science. The test was administered nation-wide and was given to a wide demographic, and as a whole, it was found that this nation's students do not possess the fundamental ability to apply scientific reasoning to everyday problems. Perhaps what is most disturbing about these findings is that the high

percentage of students demonstrating a lack of proficiency is actually an increase over similar findings from four years ago. The findings are startling, and are made worse by the fact that it is not only science that has seen shortfalls in student performance. Mathematics testing has revealed a similar lack in understanding, with only one in five of the nation's high school seniors demonstrating a proficiency in that field. [1]

George D. Nelson, head of a reform initiative of the American Association for the Advancement of Science, said schools must improve the way they teach science by setting clearer learning goals and more closely aligning curriculum materials with them. "Unless immediate actions are taken to remedy all of these shortcomings in science education, the prospects for improved science learning will remain grim for the foreseeable future," he said [1]. Furthermore, Education Secretary Roderick R. Paige said, "If our graduates [from high school] know less about science than their predecessors four years ago, then our hopes for a strong 21st century workforce are dimming just when we need them to improve most." [1]. In 2000, Congress allowed 80,000 additional work visas, largely to be issued to fulfill demand in the workforce that was centered around scientifically related fields for which there were not enough qualified Americans [1]. "There is something wrong when foreign workers are getting jobs in America because we failed to teach American graduates the skills," Paige said [1].

While only 18 percent of high school graduates could demonstrate a proficiency in science, what is worse is that only 53 percent even exhibited knowledge that ranked them at the basic level [1]. In her book, "They're Not Dumb, They're Different," Sheila Tobias investigates what it is about many students that keeps them away from the sciences. There are those students, the large majority in our nation, who shy away from

studying science because it does not appeal to them. It is to this group of students that Tobias applies the term “second tier” students. The second tier student may have different learning styles, different expectations, different degrees of discipline, different “kinds of minds” from students who traditionally like and do well in science. If science were presented in a different format, perhaps it would be more attractive to these “second tier” students [2].

It is my firm belief that providing a fundamental understanding of basic concepts in science in an enjoyable and entertaining manner would generate a higher interest in the field and consequently have an impact on the continued study of science later in life. In his book “A Brief History of Time,” Stephen Hawking states, “ ... [M]odern science has become so technical that only a very small number of specialists are able to master the mathematics used to describe them. Yet the basic ideas about the origin and fate of the universe can be stated without mathematics in a form that people without a scientific education can understand.” [3]

There has also been extensive research and studies conducted on the subject of physics education. Eric Mazur, Professor of Physics at Harvard University, has explored the nature of educating the general public in physics and has produced a number of papers and book on the subject. At the forefront of this work is Project Galileo, which Mazur, along with many others, have developed as a way to better teach physics. Some of the fundamentals of Project Galileo are the same key ideas I am exploring in my own research. Most notably are the ideas of tests before lectures to engage thinking and the incorporation of demonstrations to provide concrete examples of the ideas being presented [4].

One of the most important findings in Mazur's work is that often times, a student will alter their memory of demonstrations to match their ideas about the underlying physics. However, Mazur found that asking students to predict outcomes and to also be actively involved in the demonstrations could readily eliminate this problem [4]. Those "fixes" are also an integral part of my lectures, essentially requiring audience members to really think about what will happen and not just passively watch.

II. Theory

It is with the notion that science can appeal to, and be explained to, the general public in an understandable way that my research takes place. Through a series of demonstration-based seminars, I hope to provide some insights into the fundamental laws of physics and provide people with a better understanding of the world, which surrounds them.

Physics education theory is a subject which has received increasing attention over the last couple of decades. One pioneer in physics education, Dr. Lillian McDermott at the University of Washington, revolutionized thinking about physics education by incorporating various learning techniques and then testing the effectiveness on groups of students. The physics education group at the University of Washington is currently engaged in three major projects: improvement of student learning in introductory physics, preparation of future physics faculty, and preparation of pre-college teachers to teach physics and physical science as a process of inquiry. [6] It is the final point of research, that of engaging high school students in a question and answer scenario that I have attempted to embrace in my presentations. In one example of his work, Mazur was addressing the topic of buoyancy. Prior to discussion and his demonstrations, Mazur

noted that the class had only a cursory understanding of the principles. However, following the presentation, there was a 29 percent increase in correct answers on his surveys. He found that there is always an increase in correct answers and has never seen a decrease in all of his lectures [7]. The basic idea, which comes out of these studies is that students learn physics best when they are challenged to think about demonstrations which they see and when they are called upon to actively participate in the lecture. It is these ideas which I wish to test in my lectures.

III. Methods:

Lectures were prepared on various topics aimed at general audiences (middle school to high school level). The first few lectures were given as a Wednesday night series called “Phantastic Physics,” delivered in the Small Hall lecture hall. The lectures were advertised in the Virginia Gazette, by contacting local high schools and by hanging flyers around campus. Later, lectures were taken directly to middle school classrooms.

In an effort to gauge how much information the participants are processing, before and after each presentation all audience members receive a survey (Appendices 4-6), which asks questions related to the lecture. These surveys serve a two-fold purpose, first they provide statistical data for the researcher, but more importantly, they allow the participants to begin thinking about the concepts prior to the actual lecture so that they can formulate ideas and recall what they already know. See Appendices 4-6 for copies of the surveys.

The first lecture (Appendix 1) delivered at Small Hall focused on what are arguably the cornerstones of physics: Newton’s Laws. The seminar began with a brief history on Sir Isaac Newton, and then all three of the laws were stated. The seminar

lasted approximately 40 minutes; each law was handled individually and accompanied by a number of demonstrations that adequately depicted the effects of the law. What was most important was that the demonstrations allowed audience members to see what they had learned in action. Also, an integral part of the presentation was the hands on experiments that the audience took part in. Materials for individual demonstrations were provided so that the lectures were interactive for the participants as well. As an example of the format for exactly how a typical demonstration worked, we will use the demonstration for gravity acting uniformly on all objects. The participants are first subjected to a question such as:

“Which will hit the ground first from the same height: An apple or bowling ball?” After their decisions are made, I lead a little discussion, asking why people felt the way they did and trying to help them reason out the physics. In this example, people often used the fact that the bowling ball was heavier as a reason for why they thought it would hit first.

Following a brief discussion, I would then conduct a demonstration that revealed the physical concept in question. For our example here, a bowling ball and apple would be dropped from the same height, with the result of simultaneous impact being observed. We furthered the level of understanding by using a hands-on demonstration involving a crumpled up piece of paper and a penny, again observing that they hit at the same time. Then, we would have another discussion about what was observed and the participants could then ask questions about the concept. As a follow up, on the exit survey, the question was asked again, this time with the hopes that the concept was understood and the answer would be correct.

My general aim for the lectures was to provide a very broad understanding of a number of prevalent physical concepts. There was very little mathematical or formulaic notation; instead, I focused on drawing on the audiences everyday experiences to relate what they already knew to the laws, which governed why things are the way they are.

In the book, “Thinking Physics,” by Lewis Carroll Epstein, there is a statement that summarizes my goal of the presentations: “It has been said by more than one wise old physicist that you really understand a problem when you can intuitively guess the answer before you do the calculation” [6].

At the conclusion of my presentations, I do not expect that all members will be able to formulate exact numeric answers to questions, as we would expect from a student who has taken a course that covers the material extensively. Instead, I only hope that a participant would be able to intuit what would happen physically, and perhaps have the desire to further their course of study so that one day they may be able to find exact solutions to the problem.

A second lecture on forces, energy and work was also presented at Small Hall. A third lecture, which was a combination of the first two, was delivered to the sixth and eighth grade science classes at Williamsburg Christian Academy. A fourth lecture on magnetism is scheduled to be delivered at Toano Middle School after this thesis is due.

IV. Results:

What we saw was encouraging from a statistical standpoint. Prior to the first lecture (Appendix 1), the average on the surveys was a 75 percent number of correct responses. However, following the lecture, 91 percent of the questions were answered correctly. We had 46 attendees answer the questionnaires at the lecture, with about 55

percent being college educated, and all of the participants being at least at the grade school or high school level. We only had 4 surveys with participants currently in high school.

There was a significant improvement on questions relating to Newton's first and second law, relating to inertia and net forces, respectively. Newton's third law, the law of interaction, continued to pose difficulty even after the lecture, and so needs more time and development in lecture and with demonstrations. Questions relating to the effects of gravity were nearly unanimously understood following the lecture. As is seen in Fig. 1, all questions had a great improvement from before the lecture to after. For the actual problems corresponding to the graph below, see Appendix 4.

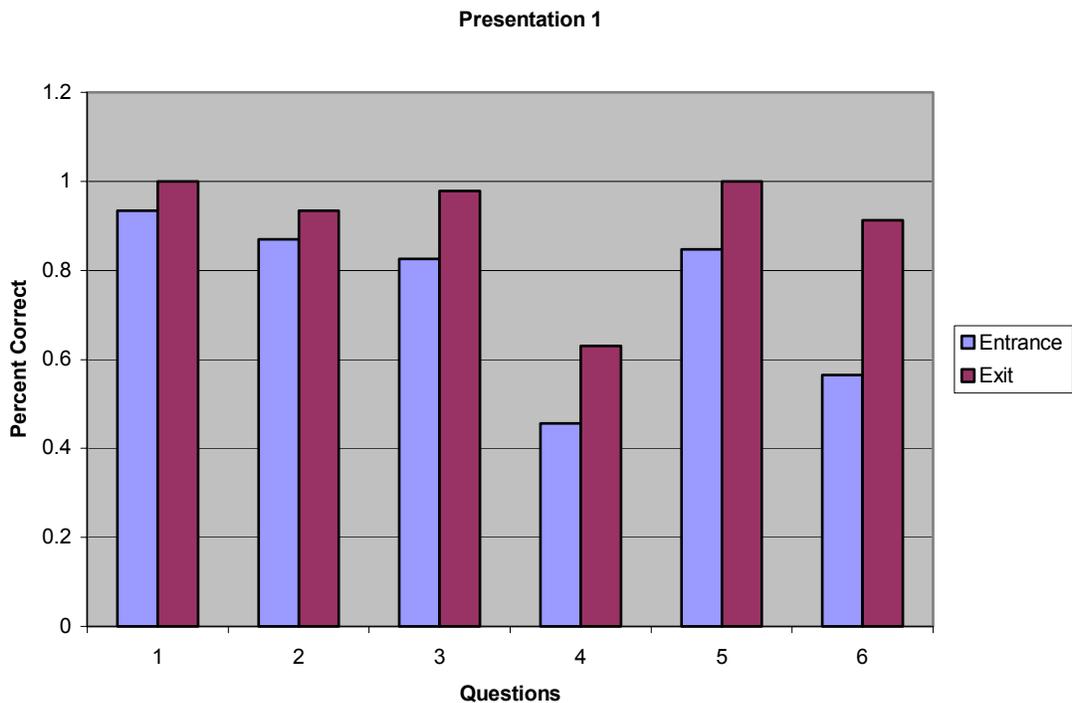


Fig.1: Percentage of correct answers for questions given at first lecture on Newton's Laws. See Appendix 4 for the accompanying questions

Although the demographic of the audience was not the intended target range, the fact that we were able to raise the level of physical aptitude of the general public was encouraging.

Lecture 2 (Appendix 2), focusing on the principals of forces, work and energy, had similar results to the first. Before the lecture, the surveys yielded 71 percent correct answers. Following the lecture, 94 percent of the questions were answered correctly. This lecture saw 39 surveys turned in. Unfortunately, we did not have any high school or lower students at the lecture. All students present were college students, and we had a small group of members from the community as well. Again, some questions were handled better than others. Prior to the lecture, most people knew that a dropped and horizontally projected ball would hit the ground at the same time. Following the lecture 100 percent answered correctly. However, question 2 had the largest improvement, and it also related to gravity pulling down a projectile. Question 2 dealt with the two ideas: first, that all objects being affected equally by gravity; second, that a horizontally projected object will hit the ground at the same time as an object simply dropped from the same height. This concept was demonstrated in the lecture by using a manufactured device, which could simultaneously project a ball while dropping another from the same height. Although there was marked improvement, there was also still a large number of wrong answers, so more work is needed on this type of question. Circular motion, and the notion that there is always an acceleration directed towards the center of the circle, posed the biggest difficulty for the participants in the second lecture. As Fig. 2 shows, there was again a large improvement over many questions, with all questions having a higher

percentage answered correctly following the lecture. For the questions corresponding to the numbers on the below graph see Appendix 5.

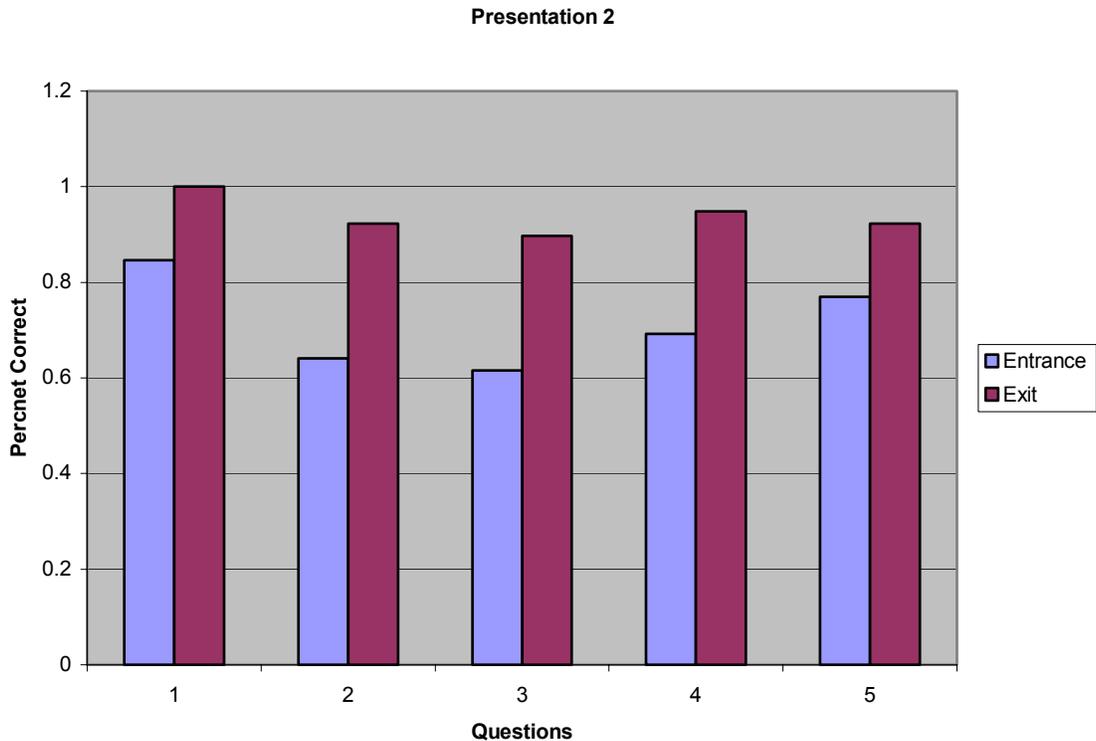


Figure 2. Percentage of correct answers for questions given at second lecture on forces, work and energy. For questions see Appendix 5.

The third lecture (Appendix 3), which was given as a combination of the first two lectures, was delivered to middle school students (6th and 8th grade) and yielded some of the most important results. On the entrance survey, the overall average of correct answers was only 42 percent, while after the demonstrations; the average had increased to 74 percent. We took in 17 surveys from the classes, and unfortunately, the results echo the statistics found in the Washington Post article, with 6th to 8th grade students having a minimal understanding of some of the most basic physical concepts. The students demonstrated little knowledge of the uniformity of gravity prior to the demonstrations.

Over 50 percent of the students chose the heavier objects to fall faster than the lighter ones. Following the lecture, 70 percent answered the question correctly. Once the concept of air resistance and retarding forces was explained, the students demonstrated a better understanding of why some objects take longer to fall than others. Newton's third law, that of interaction, was again misunderstood by nearly all. Twenty-three percent of the students had the correct answer prior to the demonstrations of equal and opposite reactions, following the demonstration, 65 percent showed an understanding of the concept. The most misunderstood concept was the relationship between potential and kinetic energy, illustrated by a person sliding down a slide. None of the students were able to answer the question correctly on the entrance survey, whereas after the lecture almost 60 percent had a better understanding of the tradeoff between potential and kinetic energy. Fig. 3 shows the results of the demonstrations given to the middle school students. For the questions corresponding to the numbers on the below graph see Appendix 6.

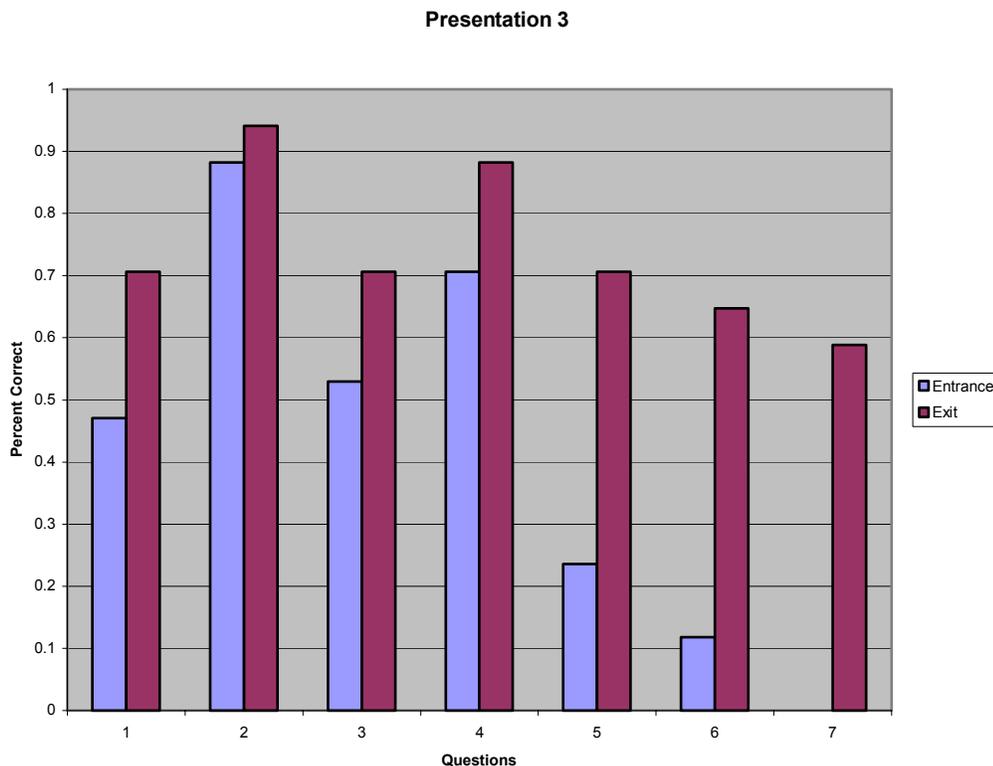


Fig.3: Percentage of correct answers for questions given at third lecture to middle school students on Newton’s Laws and forces, work and energy. For questions, see Appendix 6.

V. Conclusions:

I believe that if presented properly, physics can be so powerful and fascinating, that it can lose its stigma of being boring and difficult and instead become a popular path to choose because of its wide applications. This was made most apparent through the middle school demonstrations. The students asked many involved and thoughtful questions. Following the presentation, many came up to ask more questions and presented situations where they had perceived physical concepts and wanted explanation. This type of interaction seems to indicate that there is an underlying interest in many people to understand physics better.

The results of the three lectures indicate that there is a significant amount of information being absorbed during the presentations. Further, the interaction between lecturer and audience insures that the participants are actively involved and paying attention, as well as experiencing for themselves the effects of the discussed concepts.

The improvement on the questionnaires and the interest shown by those who attended the lectures is more than enough reinforcement of the idea that this is a worthy course of action to continue. However, there are a number of additions and changes that will further this study along.

Most importantly, having conducted the seminars to various audiences in various locations, it is apparent that the smaller the group and the more personal the demonstrations are, the better the outcome. Taking the lectures to classrooms and dealing with students in their own environment seemed to yield superior results and more feedback than the presentations made in large lecture halls. Also, more hands-on demonstrations should be incorporated to maintain a high level of audience participation. Using simple tools and props to demonstrate the concepts, and then allowing the participants to experience those concepts first hand yielded the highest levels of improvement on the surveys.

Another important addition to these demonstrations would be the development of computerized visual enhancements. For example, a program that took into account air resistance and wind as well as initial velocity and angle of launch for projectiles would add much to the discussion of projectile motion. Finally, there should be a larger number of seminars with much more focused intent. Instead of trying to glean a majority of concepts in an hour, there should be a number of presentations, each one focusing on a

specific topic, with corresponding questions, demonstrations and hands on demonstrations.

All of the above-mentioned needs are long-term goals, and should be worked on as much as possible. As is, the current method still meets the primary goal of exposing more people the nature of physics and hopefully encouraging further study of it. Further work on this project will yield better results.

Appendix 1 : First lecture delivered on Newton's Laws

Sir Isaac Newton (1642-1727)

English physicist and mathematician who was born into a poor farming family. Luckily for humanity, Newton was not a good farmer, and was sent to Cambridge to study to become a preacher. At Cambridge, Newton studied mathematics but was forced to leave Cambridge when it was closed because of the plague, and it was during this period that he made some of his most significant discoveries. With the reticence he was to show later in life, Newton did not, however, publish his results.

In Book I of *Principia*, Newton opened with definitions and the three laws of motion now known as Newton's laws (laws of inertia, action and reaction, and acceleration proportional to force).

1. (Law of inertia): A body at rest remains at rest and a body in motion continues to move at a constant velocity unless acted upon by an external force.
2. A force \mathbf{F} acting on a body gives it an acceleration \mathbf{a} which is in the direction of the force and has magnitude inversely proportional to the mass m of the body:
 $\mathbf{F} = m\mathbf{a}$.
3. Whenever a body exerts a force on another body, the latter exerts a force of equal magnitude and opposite direction on the former. This is known as the weak law of action and reaction.

What is truly amazing about these very basic laws is the broad range of events for which they are applicable. Newton's claims and ideas, at that time, were quite revolutionary, and not readily accepted. Yet today society wholeheartedly embraces these laws. The three laws govern virtually every aspect of our everyday lives. Newton's Laws explain such simple things as a ball falling, as we will see. But, they are so powerful that they were used when it came to putting things into space.

Newton also managed to suffer a mental breakdown in 1675 and was still recovering through 1679.

Many of us, when we think of Newton, have an image of a man getting hit on the head with an apple. While that event never actually took place, Newton did explore a number of the properties associated with gravity. One important fact is that gravity acts uniformly on all objects, regardless of size and mass.

Demonstration 1: Apple and Bowling ball fall

Setup: Drop a bowling ball and apple from the same height at the same time.

Under the influence of only gravity, all objects will fall to earth at the same rate. This fact is due to the uniformity of the force of gravity. However, because in the “everyday” world gravity is not the only force acting on objects, this fact is often missed.

Hands on Demo 1: Paper and Penny

Setup: Drop a penny and a piece of paper at the same time from the same height. Then crumple paper to eliminate air resistance and repeat.

Here we have a feather and a penny. Intuitively, many of us know that when dropped, a penny will fall towards the earth at a greater speed. Unfortunately, this causes a contradiction in our minds, because it would appear that gravity is pulling on the penny with a greater force. But, in fact, it is the retarding force of air resistance that delays the feathers decent. If there were no air, the feather would hit at the same time as the stone.

Demonstration 2: Feather and penny fall

While the properties of gravity are fascinating and far-reaching, we are going to step away from gravity now and focus our efforts on Newton’s Three Laws.

Newton’s First Law, as we have already stated is that:

A body at rest remains at rest and a body in motion continues to move at a constant velocity unless acted upon by an external force.

We can try to understand this by looking at our own selves in the morning. If left alone, many of us would probably just lie in bed all day, but then there is the force of our alarm clock blaring at us that causes us to move ourselves out of bed.

Ok, maybe that isn’t exactly what the laws implies, but remember; resting bodies don’t like to move.

Let’s take a look at a different, and perhaps more appropriate situation.

Hands on Demo 2: The Penny revisited.

Setup: Have students look at penny and note that it will not move until they move it.

Demo 3: Ball

Here we have a bowling ball. It isn't moving. It isn't going to move until a force comes and moves it. The ball is at rest.

Now a force, me, will act on the ball and there will thusly be motion. Now, the ball will continue to move until another force stops it. This is because a body in motion will stay in motion.

Here is another demonstration that many of you have probably seen, but now you will understand how it works.

Here we have a table set for dinner. Unfortunately, the tablecloth is dirty and needs to be removed.

Demonstration 3: Table Cloth Trick

Setup: Place a few heavy objects on top of a tablecloth. Rapidly yank the cloth out from under the objects.

The dishes and other items were all at rest, and as we know, bodies at rest tend to stay at rest, so they simply want to remain where they are, thus they don't move with the cloth. This is all because of inertia. Inertia is what keeps an object from changing its velocity. These objects had no velocity, and their inertia kept it that way.

So to recap: A body in motion will stay in motion and a body at rest will stay at rest, unless acted upon by a force.

Now on to the second law:

A force \mathbf{F} acting on a body gives it an acceleration \mathbf{a} which is in the direction of the force and has magnitude inversely proportional to the mass m of the body:

$$\mathbf{F} = m\mathbf{a}.$$

Demo 4: Force and direction

Setup: With large ball demonstrate that it will move in the direction it is pushed.

Ok, here we go with our ball again. When I push the ball, it moves in the direction in which I push it, that is because I am applying a force to it.

We can also see how forces depend on mass if we look at the interaction of a ping pong ball and a bowling ball. If we allow the ping pong ball to apply an unbalanced force to the bowling ball, we see that very little happens. Yet, if we allow the bowling ball to act on the ping pong ball we see there is a much larger resulting motion.

Hands on Demo 3: The penny, once more, and the paper too.

I would like you to put your finger on the penny and push it all around the desk. You will notice that the penny moves in the direction in which you push. The force of you pushing is what causes the penny to move. This seems very intuitive, and it is, and so is Newton's second law.

Similarly, take the piece of paper and hold it up again. Now, as you hold it there, we have a static system, which means all the forces are balanced. Most importantly is the fact that the force of you holding the paper is balancing the force of gravity. If you let go, gravity acts as the unbalanced force, and as we expect, the paper falls towards the ground.

So to recap, objects accelerate in the direction of a force.

Now on to our final Law, Newton's Third Law:

Whenever a body exerts a force on another body, the latter exerts a force of equal magnitude and opposite direction on the former. This is known as the weak law of action and reaction.

This is, perhaps, the toughest law to understand, because it seems contrary to what we know.

One classic example is the horse and cart problem that was posed on your entrance survey.

Believe it or not, the force on the buggy is as strong as the force on the horse. However, because the horse is joined to the earth by its flat hoofs, while the cart is free to roll.

What is important in this problem is the notion of mass. Because the horse is attached to the earth, it essentially has a much greater mass than the cart and thus the cart is being pulled on by the horse and earth.

Perhaps a better way to illustrate this law though, comes with our next demonstration.

Demo 5: Fire Extinguisher Cart

Setup: Have a sled on rollers, have a fire extinguisher. Sit on sled, use extinguisher for propulsion.

Here we have a fire extinguisher, which expels particles at a relatively high velocity, caused by the force of compression. Now, when the particles are expelled it is because of a force, but they are exerting a force in the opposite direction. So, if there is a force acting in the opposite direction, there can be an acceleration, which means we can have an extinguisher powered cart.

As a quick recap, a crazy dead scientist who was never hit over the head with an apple, still managed to come up with three laws that basically describe all the motions that we observe in our everyday lives, and one more time, here they are:

1. (Law of inertia): A body at rest remains at rest and a body in motion continues to move at a constant velocity unless acted upon by an external force.
2. A force \mathbf{F} acting on a body gives it an acceleration \mathbf{a} which is in the direction of the force and has magnitude inversely proportional to the mass m of the body:
 $\mathbf{F} = m\mathbf{a}$.
3. Whenever a body exerts a force on another body, the latter exerts a force of equal magnitude and opposite direction on the former. This is known as the weak law of action and reaction.

So to conclude our presentation, I would like to hand out an exit survey, that will help me to understand which demonstrations were most effective and how much you are taking away from this presentation

Appendix 2: Second lecture on Motion, Energy and Work

Lecture 2: Motion, energy and work.

Good evening and welcome to the second installment of Phantastic Physics. In our last meeting, we began our look into the physics realm with a discussion of Sir Isaac Newton and his laws of motion. As you may or may not recall, Newton's Laws can be summarized as follows:

A body in motions tends to stay in motion, while a body in rest tends to stay at rest.

Unbalanced forces cause motion in the direction of the force that is inversely proportional to the mass. (The heavier an object the smaller the acceleration will be)

And finally, every action has an equal and opposite reaction.

Demo 1: The Rocket Sled again It will work I swear.

Setup: Have a sled on rollers, have a fire extinguisher. Sit on sled, use extinguisher for propulsion.

Now, for those of you who were here last time, you will recall that we went through a number of demonstrations that investigated the properties of these laws. And, for our final demonstration, I wanted to show you my rocket-powered sled, unfortunately it was out of fuel. Well, in an effort to refresh your memory about Newton's Laws, and to prove that my rocket-powered sled actually works lets try it again.

As a quick overview of the laws, let me show you that if we do nothing to the sled, it simply will not move. Further, once we get into motion, the sled and I are going to want to stay in motion until some other force stops us. And finally, the action of the gas being expelled from the fire extinguisher causes a reaction of motion in the opposite direction.

What we have talked about thus far has been motion that has been limited to one direction, but as we all know, in our everyday lives, motion occurs in multiple directions. When motion occurs in both the horizontal and vertical direction, we physicists like to call it projectile motion.

Demo 2: Playing Catch

Setup: With assistant, throw a ball in a pronounced arc, to show parabolic path of projectile.

Anyone that has ever thrown a ball has experimented with projectile motion. As we throw this ball I want you to notice a few things. First, notice that the ball is following an arced path. This path is because when we release the ball, we are throwing it at an upward angle, but gravity is acting on the ball as well, trying to pull it back down to earth. So, as the force of gravity works on the ball, it eventually cancels out the effect of the initial upward throw, and brings the ball back down.

Also, please notice that to a reasonable approximation, the horizontal speed of the ball does not change as the ball travels. But, please do notice that as the ball travels, the vertical speed does change. When the ball gets to the apex of its vertical path, it actually stops moving in the vertical direction and then changes its direction and comes back down.

Sometimes, it is best to think of projectile motion in terms of the separate motions. If we looked straight ahead at a thrown ball, what we would see as far as vertical motion would simply be an up and down motion.

Similarly, if we were to lie down under the path of the ball, it would appear to be traveling in a perfectly straight line.

When you break the system down, you can begin to analyze some of the interesting properties of projectile motion.

One of the coolest things is to realize that because a projectile is really just two independent systems acting at the same time, we have two sets of properties acting at the same time.

Demo 3: Ball drop/Launch:

Setup: Using a device which will simultaneously drop a ball and launch a ball to the side with a horizontal velocity, show that the two will hit at the same time.

If we were to launch a ball in a perfectly horizontal direction, while at the same time, allowing another ball to drop simultaneously from the same height, they would actually hit at the same time. This is a result of gravity acting uniformly on all bodies. In the first second of motion gravity pulls on both balls at the same rate and continues to do so as the falling continues. So, while the projected ball ends up farther away, it was in the air for the same amount of time.

Demo 4: The monkey and the hunter:

Setup: Using a device which can aim a projectile at a target that will fall as soon as the trigger of the gun is pulled, show that when the projectile is aimed exactly at the target and the two reactions take place (launch and drop) they will hit.

Another fun experiment is called the monkey and the hunter. It is set up with the following little story. There is a hunter in the jungle trying to kill a monkey for a trophy. After a long day of searching, the hunter finally comes upon a monkey hanging in a tree. Unfortunately, the hunter recognizes the monkey as the very hard to hunt “quick reflex” monkey. The hunter knows that the flash of the gunpowder will cause a reaction in the monkey instantaneously. So, the hunter figures the monkey will probably just let go of the branch and fall, but the hunter needs to figure out where to aim his gun so that he can still bag the monkey. Well, as we know from our previous looks at projectile motion, that objects, such as a monkey and a bullet, fall at the same rate under the force of gravity, and we also know that projectiles follow arced paths. So, if we aim the gun right at the monkey, when the gun is fired, the monkey will fall straight down, but the path of the bullet will be in an arc, and will end up hitting the monkey on its way down.

Many years ago, people began to understand about projectile motion when it came time to storm castles. Opposing forces would line up their cannons at the edge of the moat of the enemy's moat, aim the cannons at the top of the walls and watch as the cannon balls kept falling short of the mark. Originally, it was thought that the balls went on a straight line up and then fell straight down, but eventually they found out about the arced paths of motion.

Another type of motion that can occur in the real world is circular motion. Circular motion is often a little confusing, but it is so prevalent that it is worth trying to understand. We see aspects of circular motion all over the place. From something as simple as a hammer throw in track and field to things as complicated as satellite orbits, circular motion occurs all over the place.

Hands on Demo 1: Circular motion:

Setup: Provide a washer attached to some string and allow audience to swing the device to explore circular motion.

As you came in I hope you all received a washer with a string attached to it. That is your own circular motion experiment. What we will all do now is start rotating our system. What is causing the washer to move in a circle? It has to do with the tension in the string, which restricts the motion of the washer and keeps it in the circular path. Now, in circular motion there are two very important things to remember. One is that the object is always accelerating towards the center of the circle, and the instantaneous velocity of the washer at any moment is the tangent to the circle. The acceleration towards the center is what keeps the washer moving in a circle, because as we know, a body will move in the direction of acceleration. Also, because the direction of motion is tangent to the circular motion, that means if we were to cut the string, the washer would take off in a direction tangent to the circle at that point. This is the principal behind the hammer throw competition in track and field.

Now another interesting thing that happens with circular motion, is that there is a force that is generated. The fact that there is a force should not be really surprising though, because we know from Newton's second law, that a force is simply the product of mass and acceleration, and since there is always acceleration towards the center of the circle, a force should accompany. Forces caused by circular motion are called centripetal forces, and the force is actually directed towards the center of the circle. As you were spinning the washer in a circle, the string was providing the centripetal force that kept it moving in a circular path.

A very confusing thing happens when we begin to discuss centripetal forces unfortunately. Anyone that has ever been to an amusement park and gone on a roller coaster knows that if you go in a loop, you feel significantly heavier at the bottom of the loop than at the top. People always talk about centrifugal force being the cause of this, and while this is partially correct, there is a lot of confusion.

Demo 5: Bucket o' water:

Setup: Fill a bucket with water, and swing it above your head, showing that the motion will keep the water in the bucket.

To illustrate what is going on, let's take a look at a system here made of a bucket that is filled with water. Now, as we have previously discussed there is an acceleration, and thus a force, directed towards the center of a circle, and if I swing this bucket in a circle over my head, you might think that the water will pour out on me. This doesn't happen though, and a lot of people say that it is because of centrifugal force. What is happening is that the water is in a non-inertial frame. What is happening is that the water is staying in the bucket as it balances the centripetal force with its normal force. This of course will only happen if we swing the bucket fast enough that we generate a centripetal acceleration that is greater than the acceleration due to gravity. Otherwise, if we don't swing it fast enough, I will get soaking wet.

From the perspective of an outside observer, there is no contribution of force from what we call centrifugal force. In the case of a roller coaster, the track provides the force to cause circular motion. Similarly, a car going around a turn does so due to the force of friction, and with your washer, it is the tension in the string that keeps the washer going in a circle. However, if you are in the frame of motion, then the centrifugal force is very much present and very noticeable. What is important to understand is that the presence of forces sometimes depends on the frame of reference of the observer.

We see this type of force all the time though, even though it doesn't exist. We see it when we are in a car going around a sharp turn, or as already stated when we are on looping roller coasters. It is what keeps us in our seats at the top of the loop and makes us feel heavier at the bottom.

Now roller coasters are some of the greatest physics demonstrations ever created, and they are a great way to examine the properties of energy. There are two kinds of energy that we are going to talk about: Potential and Kinetic energy. Potential energy is the kind of energy that a system has while not moving. For example, when you are at the top of the first hill of the roller coaster, you have a lot of potential energy because you are so high up. Kinetic energy is the energy of motion; after all, kinetics is the study of motion. When you are screaming through the bottom of the roller coaster, you have a lot of kinetic energy. Now, energy, like momentum, is a conserved quantity.

In a perfect world, where energy was not given up to things like heat and sound, a roller coaster could rise as high on the next hill as it was on the first, that would be because there would be a perfect tradeoff between potential and kinetic energy.

Demo 6: The pendulum:

Setup: Swing a large pendulum

Perhaps this is better demonstrated with a pendulum. When you bring the pendulum up you provide it with potential energy, and when it falls, it trades off the potential energy for kinetic energy, and then as it rises, the kinetic energy turns back into potential energy. Now when I lifted the pendulum, I was doing work on the system, and work is an integral part of energy, because doing work on a system will change the energy that the system has. Work is defined as a force times a change in displacement. So when I pulled the pendulum up, I did work on the system, which put energy into the system, and allowed motion to ensue.

It is worth noting that in the physics world, work only occurs if there is a change in displacement. That means that I can spend all day pushing on a wall, getting thoroughly exhausted and sweaty and technically have done no work.

Demo 7: Doing work:

Setup: Lift and lower a book

Now, work takes shape in a number of different forms. For example, if I lift a book, I have changed its height, and thus done work on it. I have also added potential energy to it. And, if I put the book back down, I have done work again, this time in the opposite direction, so it could be considered negative work, plus I have decreased its potential energy back to the original state.

Now, with our pendulum set up, some work is being done by the pivot at the top, due to friction, and that work depletes a little bit of the energy from the system so that the pendulum cannot come up as high as it was originally released from.

Demo 8: Loss of Energy in a pendulum:

Setup: Hold the pendulum weight up to your chin, release it and show that it will not rise as high ever again.

To demonstrate this, I need a brave volunteer to come help me. What we will do here is put the pendulum right up to their chin and just release it. Now if everything I have said is correct, the pendulum should come right back up but be just a little bit below where we released it, and that way they won't get hit in the face.

And so as you can see, even the slightest amount of work done on a system has noticeable implications on the energy of the system.

Demo 9: Mousetrap energy:

Setup: Have a box full of mousetraps with ping pong balls resting in the traps. Set off one trap and the rest will go as well.

Now, for our final demonstration, I want to show you a really fun relationship between potential and kinetic energy. What we have here is a box filled with mousetraps, with ping-pong balls as the bait. Here in my hand I have an extra ball, which I am going to drop into the box. Now all of the mousetraps have a lot of potential energy stored in the springs, and as we know, potential energy gets turned into kinetic energy, so if we can get the springs to give up their energy, we should see a lot of motion.

To recap all that we have discussed tonight: we briefly reviewed Newton's Laws of Motion, we explored the concepts of projectile motion, talked briefly about torque and angular momentum, we then discuss circular motion and finished with energy and work.

Before you leave, I would ask that you please fill out the exit surveys that were handed out to you and please drop those off on your way out. Thank you very much for attending.

Appendix 3: Third lecture, delivered to middle school students

Sir Isaac Newton (1642-1727)

In Book I of *Principia*, Newton opened with definitions and the three laws of motion now known as Newton's laws (laws of inertia, action and reaction, and acceleration proportional to force).

1. (Law of inertia): A body at rest remains at rest and a body in motion continues to move at a constant velocity unless acted upon by an external force.
2. A force \mathbf{F} acting on a body gives it an acceleration \mathbf{a} which is in the direction of the force and has magnitude inversely proportional to the mass m of the body:
 $\mathbf{F} = m\mathbf{a}$.
3. Whenever a body exerts a force on another body, the latter exerts a force of equal magnitude and opposite direction on the former. This is known as the weak law of action and reaction.

What is truly amazing about these very basic laws is the broad range of events for which they are applicable. Newton's claims and ideas, at that time, were quite revolutionary, and not readily accepted. Yet today society wholeheartedly embraces these laws. The three laws govern virtually every aspect of our everyday lives. Newton's Laws explain such simple things as a ball falling, as we will see. But, they are so powerful that they were used when it came to putting things into space.

Many of us, when we think of Newton, have an image of a man getting hit on the head with an apple. While that event never actually took place, Newton did explore a number of the properties associated with gravity. One important fact is that gravity acts uniformly on all objects, regardless of size and mass.

Demonstration 1: Apple and Bowling ball fall

Setup: See lecture 1

Under the influence of only gravity, all objects will fall to earth at the same rate. This fact is due to the uniformity of the force of gravity. However, because in the "everyday" world gravity is not the only force acting on objects, this fact is often missed.

Hands on Demo 1: Paper and Penny

Setup: See lecture 1

Here we have a feather and a penny. Intuitively, many of us know that when dropped, a penny will fall towards the earth at a greater speed. Unfortunately, this causes a contradiction in our minds, because it would appear that gravity is pulling on the penny with a greater force. But, in fact, it is the retarding force of air resistance that delays the feathers decent. If there were no air, the feather would hit at the same time as the stone.

While the properties of gravity are fascinating and far-reaching, we are going to step away from gravity now and focus our efforts on Newton's Three Laws.

Newton's First Law, as we have already stated is that:

A body at rest remains at rest and a body in motion continues to move at a constant velocity unless acted upon by an external force.

We can try to understand this by looking at our own selves in the morning. If left alone, many of us would probably just lie in bed all day, but then there is the force of our alarm clock blaring at us that causes us to move ourselves out of bed.

Hands on Demo 2: The Penny revisited.

Setup: See lecture 1

Demo 3: Ball

Setup: See lecture 1

Here we have a bowling ball. It isn't moving. It isn't going to move until a force comes and moves it. The ball is at rest.

Now a force, me, will act on the ball and there will thusly be motion. Now, the ball will continue to move until another force stops it. This is because a body in motion will stay in motion.

So to recap: A body in motion will stay in motion and a body at rest will stay at rest, unless acted upon by a force.

Now on to the second law:

A force \mathbf{F} acting on a body gives it an acceleration \mathbf{a} which is in the direction of the force and has magnitude inversely proportional to the mass m of the body:

$$\mathbf{F} = m\mathbf{a}.$$

Demo 4: Force and direction

Setup: See lecture 1

Ok, here we go with our ball again. When I push the ball, it moves in the direction in which I push it, that is because I am applying a force to it.

We can also see how forces depend on mass if we look at the interaction of a ping pong ball and a bowling ball. If we allow the ping pong ball to apply an unbalanced force to the bowling ball, we see that very little happens. Yet, if we allow the bowling ball to act on the ping pong ball we see there is a much larger resulting motion.

Hands on Demo 3: The penny, once more, and the paper too.
Setup: See lecture 1

I would like you to put your finger on the penny and push it all around the desk. You will notice that the penny moves in the direction in which you push. The force of you pushing is what causes the penny to move. This seems very intuitive, and it is, and so is Newton's second law.

Similarly, take the piece of paper and hold it up again. Now, as you hold it there, we have a static system, which means all the forces are balanced. Most importantly is the fact that the force of you holding the paper is balancing the force of gravity. If you let go, gravity acts as the unbalanced force, and as we expect, the paper falls towards the ground.

So to recap, objects accelerate in the direction of a force.

Now on to our final Law, Newton's Third Law:

Whenever a body exerts a force on another body, the latter exerts a force of equal magnitude and opposite direction on the former. This is known as the weak law of action and reaction.

This is, perhaps, the toughest law to understand, because it seems contrary to what we know.

One classic example is the horse and cart problem that was posed on your entrance survey.

Believe it or not, the force on the buggy is as strong as the force on the horse. However, because the horse is joined to the earth by its flat hoofs, while the cart is free to roll.

What is important in this problem is the notion of mass. Because the horse is attached to the earth, it essentially has a much greater mass than the cart and thus the cart is being pulled on by the horse and earth.

Perhaps a better way to illustrate this law though, comes with a discussion about a boater stranded on a lake. If the boater had a really heavy rock in the boat, they could throw the rock off the back of the boat to get themselves moving forward. The action of the rock being thrown off the back of the boat, has a reaction of the boat moving forward.

As a quick recap:

1. (Law of inertia): A body at rest remains at rest and a body in motion continues to move at a constant velocity unless acted upon by an external force.

2. A force \mathbf{F} acting on a body gives it an acceleration \mathbf{a} which is in the direction of the force and has magnitude inversely proportional to the mass m of the body:

$$\mathbf{F} = m\mathbf{a}.$$

3. Whenever a body exerts a force on another body, the latter exerts a force of equal magnitude and opposite direction on the former. This is known as the weak law of action and reaction.

So far we have only discussed one-dimensional forces, but what about motion in more than one direction?

Demo 2: Playing Catch

Setup: See lecture 2

Anyone that has ever thrown a ball has experimented with projectile motion. As we throw this ball I want you to notice a few things. First, notice that the ball is following an arced path. This path is because when we release the ball, we are throwing it at an upward angle, but gravity is acting on the ball as well, trying to pull it back down to earth. So, as the force of gravity works on the ball, it eventually cancels out the effect of the initial upward throw, and brings the ball back down.

Also, please notice that to a reasonable approximation, the horizontal speed of the ball does not change as the ball travels. But, please do notice that as the ball travels, the vertical speed does change. When the ball gets to the apex of its vertical path, it actually stops moving in the vertical direction and then changes its direction and comes back down.

Sometimes, it is best to think of projectile motion in terms of the separate motions. If we looked straight ahead at a thrown ball, what we would see as far as vertical motion would simply be an up and down motion.

Similarly, if we were to lie down under the path of the ball, it would appear to be traveling in a perfectly straight line.

When you break the system down, you can begin to analyze some of the interesting properties of projectile motion.

One of the coolest things is to realize that because a projectile is really just two independent systems acting at the same time, we have two sets of properties acting at the same time.

Demo 3: Ball drop/Launch:

Setup: See lecture 2

If we were to launch a ball in a perfectly horizontal direction, while at the same time, allowing another ball to drop simultaneously from the same height, they would actually hit at the same time. This is a result of gravity acting uniformly on all bodies. In the first second of motion gravity pulls on both balls at the same rate and continues to do so as the falling continues. So, while the projected ball ends up farther away, it was in the air for the same amount of time.

Energy is another very common thing to discuss in physics, and we can use some of our previous examples as well as some of our common experiences to better understand energy.

Now roller coasters are some of the greatest physics demonstrations ever created, and they are a great way to examine the properties of energy. There are two kinds of energy that we are going to talk about: Potential and Kinetic energy. Potential energy is the kind of energy that a system has while not moving. For example, when you are at the top of the first hill of the roller coaster, you have a lot of potential energy because you are so high up. Kinetic energy is the energy of motion; after all, kinetics is the study of motion. When you are screaming through the bottom of the roller coaster, you have a lot of kinetic energy. Now, energy, like momentum, is a conserved quantity. In a perfect world, where energy was not given up to things like heat and sound, a roller coaster could rise as high on the next hill as it was on the first, that would be because there would be a perfect tradeoff between potential and kinetic energy.

Similarly, we can look back at the demo when we held the piece of paper up. When it was being held it had potential energy, which was turned into kinetic energy once the paper was released.

And finally, when we were playing catch, if we were to look only at the vertical motion, we would see that as the ball rises it gains potential energy and eventually loses all its vertical kinetic energy when it reaches the top of the path.

Today we have talked about some of the very fundamental aspects of physics such as Newton's Laws, motion and energy. I hope that this has given you a little bit of an idea of how important physics is in your everyday life and how physics is always all around you.

Appendix 4: Survey accompanying Lecture 1

1. Under only the force of gravity, if you drop a bowling ball and an apple off of a desk at the same time which will hit the floor first?
 - a) bowling ball
 - b) The apple
 - c) Neither, they will hit at the same time

- 2a. If you drop a feather and a penny at the same time, which will hit the ground first?
 - a) The feather
 - b) The penny
 - c) They will hit at the same time.

- 2b. If you drop a feather and a penny at the same time, without any air resistance, which will hit the ground first?
 - a) The penny
 - b) The feather
 - c) They will hit at the same time

3. A book slides across a desk at a uniform speed and in one direction, so obviously there is an unbalanced force on the book:
 - a) In the direction of the motion
 - b) In the direction opposite of the motion
 - c) There is no net force

4. You push up against a wall with all your force, but the wall does not move. In fact, the wall is pushing back on you with:
 - a) More force, that's why it isn't moving
 - b) Less force, walls can't push anyway
 - c) The same force, nothing is moving at all

5. There is a horse pulling a cart with a constant force, so:
 - a) The forces are equal
 - b) The horse exerts a greater force
 - c) The cart exerts a greater force

Appendix 5: Survey accompanying Lecture 2

1. If you simultaneously drop a ball from a certain height and throw another ball to the side at the same time, which will hit the ground first?
 - a. The dropped ball
 - b. The thrown ball
 - c. They will hit at the same time

2. A jungle ranger spots a monkey hanging from a tree and takes careful aim with his tranquilizer gun so he can capture the animal. The ranger knows that the sound of the gun will cause the monkey to let go of the tree the moment the gun is fired. So, the ranger aims his gun:
 - a. Above the monkey
 - b. Right at the monkey
 - c. Slightly below the monkey
 - d. Half way between the monkey and the ground

3. Objects that travel at a constant speed in a circle have which of the following properties:
 - a. No acceleration
 - b. A constantly changing acceleration around the circle
 - c. An acceleration directed outwards from the circle
 - d. An acceleration directed towards the center of the circle

4. Which of the following frictionless slides will give a person the fastest speed at the bottom:



They are all the same.

5. In which of the following examples is there no work being done:
 - a. A person lifting a book off of the floor onto a table
 - b. A person pushing up against a wall
 - c. A pendulum swinging back and forth

Appendix 6: Survey accompanying Lecture 3

1) Under *only* the force of gravity, if you drop a bowling ball and an apple off of a desk at the same time which will hit the floor first?

- a) The bowling ball
- b) The apple
- c) Neither, they will hit at the same time

2a) If you drop a feather and a penny at the same time, which will hit the ground first?

- a) The feather
- b) The penny
- c) They will hit at the same time.

2b) If you drop a feather and a penny at the same time, *without any air resistance*, which will hit the ground first?

- a) The penny
- b) The feather
- c) They will hit at the same time

3) You push up against a wall with all your might, but the wall does not move. In fact, the wall is pushing back on you with:

- a) More force, that's why it isn't moving
- b) Less force, walls can't push anyway
- c) The same force, nothing is moving at all

4) There is a horse pulling a cart with a constant force, so:

- a) The forces exerted by horse and cart are equal
- b) The horse exerts a greater force
- c) The cart exerts a greater force

5) If you simultaneously drop a ball from a certain height and throw another ball to the side at the same time, which will hit the ground first?

- a. The dropped ball
- b. The thrown ball
- c. They will hit at the same time

6) Which of the following frictionless slides will give a person the fastest speed at the bottom:



They are all the same.

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