USING PHET SIMULATIONS IN THE PHYSICS FIRST CLASSROOM:

AN ALTERNATIVE TO TRADITIONAL LABORATORIES AND TEACHING STYLES

by

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A Master's Paper

Submitted to the Graduate Faculty

in partial fulfillment of the requirements of the Degree of

Master of Science in Education - Physics

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Advisor's Signature

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Date

University of Wisconsin - River Falls
November 18, 2013

Abstract

At the heart of every high school science course are laboratory activities. Through these activities, students interact with the course content in a way that provides meaningful actions to add to their overall learning experience. However, at times, the content in physics courses becomes difficult to replicate in a typical high school laboratory. By using PhET Interactive Simulations, teachers around the world are able to add hundreds of new learning opportunities to their classrooms in just a few clicks of a mouse. The simulations can be an effective way to provide high-level physics instruction to a diverse population of students. Using two particular PhET simulations (*The Collision Lab* and *Masses and Springs*), it was shown how simulations can not only take the place of some laboratory activities, but enhance the ability for students to achieve learning outcomes.

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I. Literature Review

PhET Interactive Simulations have been an active part of many physics classrooms across the country for several years. This suite of interactive simulations (http://phet.colorado.edu) was founded has been developed by the University of Colorado, and has expanded in recent years to include simulations in the areas of chemistry, biology, earth science, and math. The term "PhET" originally was an acronym for "Physics Education Technology". Because of the expansion into other fields of science, the term is limiting in its grasp. However, the acronym has remained the title of the website due to the large following it had already established in the world of education (What is PhET, 2013). The purpose of the project was to introduce new, research-based ways for students to experience physics. The simulations allow students to view situations they otherwise would not be able to, such as building atoms from subatomic particles or a more in-depth look at properties of gases. PhET has gained in popularity over the years, largely because of the fact that it is completely free for users. The website is completely funded through grants and donations. It is also useful for any student interested in physics, including many simulations that are appropriate for middle school classrooms. Nearly every aspect of physics covered in an introductory course at the high school or college level is addressed in some way through at least one PhET simulation. The simulations themselves are Java-based animations that are available for download or can be operated online. The animations are generally basic in terms of the simplicity of their design, but offer users a chance to experience advanced physics topics in a way that they can comprehend with little to no help.

Much research has been done to determine the effectiveness of PhET designs and to improve them. The PhET design team has an evaluation rating system in which they share with users the status of their simulations (PhET Legend, 2013). They also have a clear design process that the team follows before and after releasing a simulation for public use (PhET Simulation

Design Process, 2013). Some of the educators associated with PhET have collaborated to research the effectiveness of the simulations at both the secondary and post-secondary levels. Their results are similar to the findings I have made in my experiences working with PhET simulations. It is my belief that when used properly, simulations can enhance the classroom experience and increase the learning capability of the average physics student. Research from the developers of PhET indicates similar findings (Wieman, 2010; Finkelstein, 2006).

I believe that the use of PhET Interactive Simulations in the classroom has many advantages in addition to those mentioned above. For instance, students are often able to gain a general understanding of a concept by repeated inquiry, even if their background knowledge in a topic is limited (Chase, 2010). PhET simulations provide nearly perfect conditions for students to explore and discover. The controls are very user-friendly, and the measurements are generally complete with units and are easy to find and read. In most cases, multiple independent variables can be tested with ease. Students who have access to these simulations have access to nearly all the various controls and conditions they would if these experiments took place in a laboratory. Moreover, the ease in which students can manipulate these controls and conditions far surpasses any lab scenario one would find in a typical classroom setting. In fact, the simulations make many previously untouchable activities available for physics students. This is an inherent advantage over the incomplete content of textbooks and the limited nature of many traditional laboratory activities.

One difficult hurdle that many physics teachers have to overcome is one of getting students to be engaged in the material they are studying and interested in the results of their laboratory work. A student who is motivated to work with the content and use it as a learning tool is more likely to invest the time and effort needed to excel (Wieman, 2008). I have found PhET activities to be highly engaging for students. Most students enjoy the rigor involved in manipulating the controls of each simulation to find results, both expected and unexpected. It is my experience that students are interested for a longer period of time with PhET simulations, as their time is not encumbered with setting up equipment that is unfamiliar to them or reading instruments with which they have little to no experience. PhET simulations keep students engaged by continually challenging them without the students feeling like they have been challenged. A recent article from David Read (2013) at the Royal Society of Chemistry stated:

To maximize their value to learning, the simulations are designed to support inquiry without explicit guidance through the use of implicit scaffolding. This allows students to be guided without feeling guided, and encourages them to proceed at a pace that avoids cognitive overload.

Thus, students are finding new and engaging ways to interact with the program without needing a teacher or a textbook to tell them to do so. While it does not completely eliminate the need for these resources, of course, it does offer an exciting alternative to traditional physics coursework.

II. Justification for the Development of this Project

The course I teach is a required course for nearly all freshmen at Cashton High School in Cashton, Wisconsin. CHS is a small, rural school that serves approximately 35-40 freshman students annually. The course is titled Foundational Physics. It is a course that emphasizes "Physics First", which is a growing trend in education that adjusts the traditional sequence of high school science courses (Biology - Chemistry - Physics) by swapping the places of Physics and Biology. The theory is that students who have a fundamental understanding of physics are better equipped to succeed in chemistry and biology. Much of Foundational Physics involves topics similar to what one would typically find in a physical science course. As a result, the bulk of the physics in the course involves kinematics and mechanics in one and two dimensions.

Topics such as sound waves, light waves, and electricity and magnetism are covered in the second semester on a limited basis, but the bulk of the work in those topics is saved for the physics course that we offer for seniors. Therefore, my use of PhET simulations in the foundational physics course is limited mostly to topics involving one or two-dimensional motion. My belief is that while traditional laboratory experiments are an important part of any science course curriculum, students could learn physics concepts just as effectively through simulations. In fact, I believed that with high-quality activities and proper instruction and guidance on my part, my students would learn more effectively by utilizing the simulations than they would with a “hands-on” lab activity.

My first task to properly utilize the simulations effectively was to design activities that would enhance the classroom work students were already doing. In my previous attempts in using PhET simulations in the classroom, I had either used them as a demonstration with the use of a SMART board, or I had used modified versions of teaching activities other teachers posted to the PhET website. Each simulation has an area where teachers (or anyone) can access activities designed by other science teachers for use in their classroom. These activities and the ideas they provided me are extremely valuable resources in utilizing the simulations. However, to gain the maximum benefit from the website, I needed to design my own activities so that they better align to my classroom and teaching style. Rather than starting from scratch, I decided the best approach was to adapt activities that I had previously used in the laboratory to PhET simulations. In this manner, I felt that I was most likely to achieve the same objectives and learning outcomes as in the lab, while being more efficient through the use of simulations.

III. Design of the Curriculum Development Project

Initially, I made the decision to primarily focus on two physics concepts for my study: conservation of momentum and conservation of energy. This decision was made for a variety of reasons. First, these two topics are areas in which students have some background knowledge. They have likely studied energy and momentum and the related concepts in previous courses, but they do not have a firm grasp of the topics. I believed this would enable students to adapt more quickly to the vocabulary involved with each topic, but they would still need to complete the work involved with the simulations to gain a more comprehensive understanding. Secondly, the PhET website had multiple simulations to choose from that use these concepts. For the conservation of momentum activity, I decided to use the "Collision Lab" (http://phet.colorado.edu/en/simulation/collision-lab). The lab activity that I used previously for conservation of momentum involved initiating collisions between balls of various sizes (bocce, tennis, golf) and making measurements before and after the collisions. The Collision Lab (Figure 1) features two round objects on the main part of the screen that are designed to be slammed into each other.

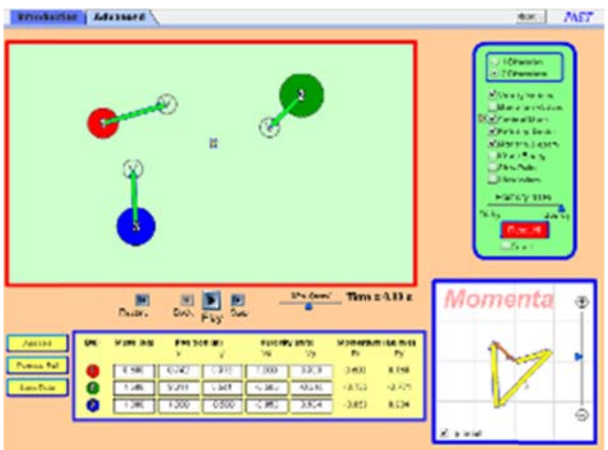

Figure 1: The Collision Lab Simulation from PhET

Users of the simulation can choose to vary the mass, the position (in two dimensions), and/or the velocity (also in 2-D) of either or both of the objects. There are tabs available called "introduction" and "advanced" that give various options to users and several check boxes that give further descriptive information about what is happening while the objects are in motion. Because the user can select any and all relevant features of the colliding objects, the possibility of an error in measurement is virtually eliminated. I believe this feature is one of the strongest positive attributes of an argument for including simulations in the classroom. Simulations offer an option for students to see that their data could actually produce the exact same result as the homework problem they worked on earlier. Error analysis is certainly a skill with which physics students need to immerse themselves, however, having the option of neglecting errors in measurement is one that can save hours of useful class time for courses already stretched to the limit.

The PhET website offers several different websites that involve the concept of conservation of energy. For this project, I chose to use the "Masses & Springs" simulation (http://phet.colorado.edu/en/simulation/mass-spring-lab). This simulation involves three springs of varying spring constant hanging from a wall (Figure 2). The user attaches a mass to the end of a spring and can manipulate several factors while making measurements.

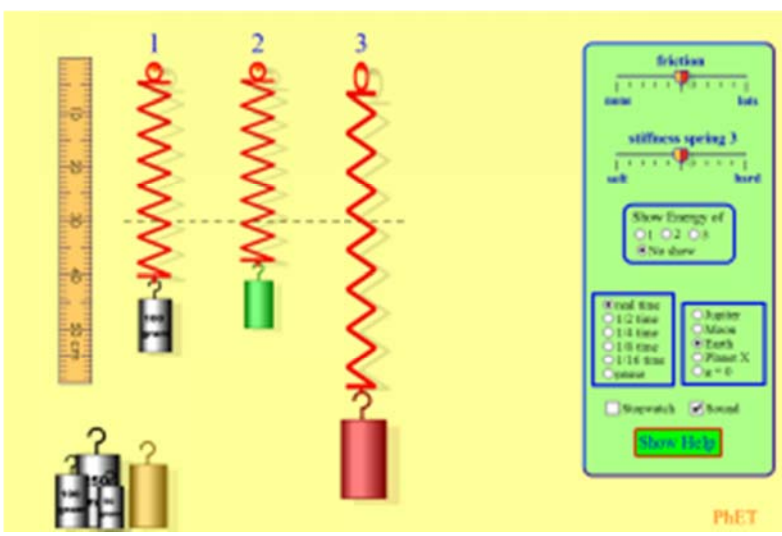

Figure 2: The Masses and Springs Simulation from PhET

Much like the Collision Lab, the simulation greatly reduces, and often eliminates, the errors in measurement that would typically be found in a laboratory activity with hanging masses. On the screen appear three springs and a handful of masses near the bottom of the window. A couple of sliders appear in a large, green box to the right, along with a small rectangles containing other options for the user to select. Users have a variety of options available to them in what otherwise appears to be a rather simple set up. One of the defining attributes of these two simulations is the simplicity with which they work. Both are very simple for students to operate. Most students are able to figure out the parameters and variables in just a few minutes of experimenting on their own. While I did provide a very detailed procedure, students typically began the simulations by simply exploring the controls and were able to begin the activity in a timely manner with few problems. Aside from designing the activities, my primary role in this activity was as a facilitator. The procedures that were provided to the students were detailed, but students still had a variety of questions as they progressed through the simulation. As an educator, it is a struggle with this type of activity to provide the needed guidance to students without drawing conclusions for them. While some gentle guidance to students who are having trouble making the proper connections is often warranted, I hesitate to answer too many questions or give too much information out at this point in the activity. This has proven to be difficult for me with not only these activities, but with other PhET simulations I have used in the past. However, when I have allowed students to draw their own conclusions and complete the inquiry process, I have found it to be a superior method to nearly any other laboratory activity I have used.

IV. Results

As I mentioned earlier, I have been dabbling with the use of the PhET simulation website for a few years. It was not until this project that I decided to take a hard look at the results, and attempt to determine whether or not the simulations had a positive impact on my classroom. This study involved 43 total students, 22 of whom were male. These students were all enrolled in two separate sections of the Foundational Physics course that I teach. After an in-depth examination of the simulations, I believe that, as a whole, they have more benefits than drawbacks. The first benefit that stands out to me is the engagement in the activities that the students have, particularly those students who struggle in a traditional classroom setting. Science courses by their nature lend themselves to hands-on activities and more student interest. However, I have found that many students find laboratory activities to be just another project for them. Many of my at-risk and special needs students struggle with work in the laboratory, but they really enjoy working on computers. Although the challenge becomes keeping them focused on their assignment rather than simply playing around with simulations, most students are more willing to work their way through the computer activities than through lab work. Another obvious benefit of simulations is that, in most cases, measurements come with a high degree of precision. In most of the simulations, the user is able to choose the parameters that he/she wishes to use for the given task. There is no need to place anything on a scale or measure an amount of liquid; those values appear right on the screen with no error at all. Another significant benefit of the simulations is that little to no equipment is used (other than a computer). Again, using instruments and materials is a part of the scientific process. Students should learn to handle equipment properly, follow proper safety guidelines, and utilize any resources at their disposal to follow the scientific method to its fullest. But in a typical classroom setting with 47 minute class periods, valuable class time is often lost setting up and taking down lab equipment.

Additionally, if a student or lab group does not complete their tasks in the allotted amount of time, they likely have to wait until the next day to complete their work. A student working with a simulation simply needs to find a computer with internet access at any point in the next 24 hours to continue or restart their work. All of this does not even consider the possibility that the equipment falters or is inefficient or the fact that multiple trials of an experiment might require a significant amount of time to reset.

I have already discussed some of the negative outcomes of using simulations, either potential or realized. Students using simulations will generally work with a high degree of precision, which is a positive characteristic but this precision limits the student's ability to analyze errors in experimentation. Users of simulations will not actually have their hands on any objects besides a keyboard and a computer mouse. One of the significant downfalls of solely using simulations would be the fact that students do not learn to operate equipment or apply safety rules. All of the traits that go with using measurement tools and other equipment are invaluable to scientists. Obviously all of the simulations are grounded in real-life situations and applications, and I would maintain that in most cases, students would be best served by experiencing both the simulation and the real-life experience, should time permit. Another drawback of simulations is that students can often become distracted from their actual activity. The simulations are generally very fun and engaging, which is a good thing, but students often overreact to this and tend to "play around" with the simulations. One question that I often hear when students find out we have a simulation to work on is, "Which game are we playing today?" While I appreciate the fact that students enjoy the simulations to the point that they call them games, I occasionally have a hard time keeping kids on task. However, this problem is not unique to any particular activity in a high school science course, and so its particular presence in a simulation activity is not especially surprising.

As a general statement, I believe that students who participated in the use of PhET simulations in the topics of momentum and energy conservation performed better on tests and on the activities themselves. One clear advantage that was noticeable to me almost immediately was that students were able to get to work more quickly with the PhET activities than they have in the past using traditional labs. Logging onto a website using a laptop or an iPad is much easier for students than setting up a detailed laboratory experience. My students were able to explore more independently, as they were not held back by having to move through the difficult process of managing their space and materials. I believe this led to more engagement with the actual science at hand, and therefore led to a better performance. While I did not compare test results to another group, students who completed the simulation had a stronger understanding of the science and vocabulary involved in the two areas of study than students in the same class in previous years. Test scores were higher than in years past. Additionally, in our class discussion after the experiment, students were more easily able to verbally articulate the vocabulary more easily and had a greater comprehension of the key objectives covered. I do not believe they would have had this same level of understanding with common laboratory activities and textbook work. In particular, I believe the students with special needs who took place in these activities realized even more relative improvement than their peers. In my experience, most special needs students tend to take a secondary role when working on lab activities. These students tend to allow other students take the lead when setting up equipment and finding and analyzing results. Even when paired with each other, a group of special needs students often waits for a teacher to offer help and, in many cases, direct the group through the process. However, when working on the PhET simulations, these same students were confident not only in completing the activities, but with engaging with their classmates in a productive manner. Some of the reason for this was likely due to the fact that by the time we explored momentum and energy conservations, we had used the PhET website a number of times. This helped to ease some of the anxiety that these students might feel while trying to "set up" the experiment. They were able to focus on their work and more quickly and efficiently move through the assigned tasks. Once again, it is my observation that all students see some improvement while working with the simulations, but the positives can be even more enhanced with special needs students.

V. Reflection

I began my MSE coursework at UW-River Falls before I actually began teaching physics. In fact, I hadn't taught science at any level when I began my coursework. With that in mind, it is fair to say that my time at River Falls has helped me with virtually everything I have done in the physics classroom since that time. I learned about PhET after I discovered it during my first year teaching physics, but I didn't appreciate its value as a teaching tool until I worked on it in the Electricity and Magnetism course offered by Matthew Vonk. A portion of the course was spent building circuits through a couple of the PhET simulations. These activities proved to be valuable to me, primarily because of my lack of knowledge in working with circuits. I really struggled when it came time to apply what I had learned in the classroom in a more practical setting. Things were very confusing to me, as I not only struggled with the content of the course, but also in working with the materials themselves. However, when we went to the laptops to use the simulations, everything seemed to be much simpler to operate. I could play around with the materials much more freely and try different things. When I failed to get the result I expected, I knew it was because I was missing something conceptually, not because I failed to operate the equipment effectively. This made me realize that many of my students probably had feelings similar to those I was experiencing. They were making mistakes, but didn't have any idea what to do next. Their only recourse was to consult the teacher, who would guide them in the right direction. I felt a sense of freedom in being able to take my time, as I wasn't necessarily restricted to the arbitrary classroom hours the schedule permitted. If I didn't understand something, I just had to make sure my laptop was charged, and I could plug away for as long as I needed until I felt comfortable. This was a bit of an "a-ha" moment for me, and I immediately began looking for alternatives to traditional lab activities. I later used simulations in other UW-RF courses and found similar results.

The first change I will make in this activity for next year is to make it more of an inquiry-based activity. While I do utilize inquiry-based labs at times in my freshman course, I also use "cookbook-style" activities when time is a factor. Generally, it is a matter of time. Cookbook-style labs seem to take less time for freshman students, although I prefer the rigor and added responsibility that is inherently a part of inquiry-based labs. I believe the conservation of momentum lab will be more successful by framing the basis of the activity with a question like, "Changing which physical properties of an object cause it to have more or less momentum? Justify your answer using data from the simulation." Although the simulation will likely lead the students to the correct answer, the key will be to get them to use data to justify their statement. I have found this to be a huge deficiency in young high school students. They often struggle with forming conclusions based on gathering data in a sound, scientific manner. The benefit of an inquiry-based model is that students need to do their own work and determine the importance of certain variables, as well as identify data that will further their conclusion. I believe that because of the user-friendly nature of most of the PhET simulations, I will be able to properly act as a leader in guiding students in the right direction in finding sound conclusions.

One of the more prominent aspects of the PhET program is its versatility. In this way, the PhET simulations can serve as a way to help students master the tiered levels of Bloom's Taxonomy. To illustrate this point, I feel it would be best to cite an example. This is certainly not the only example that could be found using the various simulations, but a simple, common demonstration of just how many uses there are for the simulations.

Like many of the simulations, at face value, the Masses and Springs simulation (Figure 2) looks to be a fairly simple animation. However, the guidelines PhET has established for inquiry activities encourage a process by which students engage in activities that have the potential to guide students to various levels of learning outcomes (Creating PhET Activities, 2013). Teachers who use this process will create activities that challenge students to reach different levels of Bloom's Taxonomy. The simplicity of the simulations does not outline the variety of learning outcomes that can be achieved using PhET simulations as the primary learning tool. For instance, by utilizing the Masses and Springs simulation, novice students can begin their *knowledge* of types of energy by working with the masses. With minimal guidance from a teacher, students can discover the basics behind the concepts of kinetic energy, elastic energy, and gravitational potential energy. By dropping a mass on a spring and viewing one of the graphs, students will rapidly notice the "total E" dotted line that bounds the top of the bar graph and reflects the total energy present in the system. My students did not need much time to *comprehend* how to raise or lower the total energy level and which combinations of energy most efficiently accomplished this process. Maximizing the elastic potential energy is an *application* that could prove to be useful in some real-life applications. Students can also be guided through this task relatively easily. *Analyzing* the trade-off between energy levels was the primary task that students were asked to accomplish in the activity they completed in my class. This is not something that is easily attainable solely by use of the simulation, but I believe that my students had a better grasp of conservation of energy as a result of the activity. Laying the groundwork for the potential for more advanced projects is something that the PhET simulations can accomplish. A possible *synthesis* activity for students after they have worked with the Masses and Springs simulation would be to have students consider how to manufacture a spring that maximizes elastic potential energy. Finally, a potential *evaluation* task might read something like, "Compare the role of a spring in producing and storing energy to that of another energy source." Clearly, more work would need to be done to complete a synthesis task or a proper evaluation, but the start of the process for a student might well begin with a look at a PhET simulation. Of course, it is unlikely that a complete mastery of gas properties is likely after a class period or two spent simulating the topic, but one can easily see the broad spectrum of possibilities for students.

With this project, I have confirmed many of the beliefs I had about interactive learning models such as simulations. They are an effective way to teach many physics concepts, and serve as an acceptable alternative to more traditional methods such as lab activities and textbooks. The process made me think more about differentiation within the classroom. While I have usually used each of the simulations to meet one or two select objectives, working with the project has gotten me thinking more about how to use the simulations to meet the needs of a more diverse group of learners. I believe that the simulations might be a welcomed alternative to traditional labs for students with special needs who otherwise struggle with more traditional lab work. Moving forward, I will give more thought to incorporating PhET simulations in a different manner, with more of a focus on independent, inquiry-based learning. Professionally, I would like to eventually contribute to the PhET site more actively. I would like to come up with at least one new activity to post to the website. After having viewed and used the results of the hard work of many other excellent teachers, I feel like I have some ideas to add. This would be an excellent way to further my professional development along these lines. This project has been a clear demonstration of how PhET simulations can be a tool that will help advance the knowledge and skills of both students and teachers alike.

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APPENDIX A: Conservation of Momentum PhET Activity

Dart Momentum

Objective: To find estimates the respective speeds of toy cars and darts using conservation of momentum after a collision between the objects.

Materials: Computer with internet access

Procedure:

1. Go to http://phet.colorado.edu
2. Click on the orange "Play with Sims" button near the center of the page.
3. Click on the "Physics" tab on the left of the page.
4. Open the simulation called "Collisions Lab".
5. Click the green "Run Now" button.
6. Click the "Advanced" tab at the top of the screen.
7. Click the "More Data" button to the left of the data table at the bottom of the page.
8. Explore the simulation by sending one or both of the balls in motion. Pay attention to how the values in the boxes on the bottom of the screen are changing.
9. Follow the directions below.

Data Collection

10. Set the Position y-values for both objects so that they are the same. The balls should line up horizontally from each other.
11. Set the mass of the red ball to (Mass of dart x 10).
12. Set the mass of the green ball to (Mass of car x 10).
13. Set the x-velocity and y-velocity of the green ball to 0.000.
14. Set the x-velocity of the red ball to 2.000.
15. Set the y-velocity of the red ball to 0.000.
16. In the green rectangular box on the right, slide the bar at the bottom so that the Elasticity is at 0%.

17. Record the values that you just entered here.

Mass of red ball = __________________

Mass of green ball = __________________

Combined Mass of red and green ball = ______________________

Initial x-velocity of the red ball = ______________________

Initial x-velocity of the green ball = ______________________

18. Press “Play” to start the motion. After impact (and before the balls hit the wall), pause the simulation. Record the following data.

X-velocity of red/green upon impact (after collision) = __________________

19. What is the equation for momentum?

____

20. What is the total amount of momentum AFTER the collision? Show your work below.

21. What is the total amount of momentum BEFORE the collision? Note that you will have to include both balls in your answer. Show your work below.

22. What does the law of conservation of momentum state?

23. Use the equation for conservation of momentum to verify the initial speed of the red ball before the collision.

(Mass of red) x (Initial speed of red) + (Mass of green) x (Initial speed of green) =
(Combined mass of dart and car) x (Speed of car upon impact)

Initial speed of dart (computed) = ______________________________

Analysis

24. How does the speed of the dart you computed in Step 23 compare with the speed you entered in Step 14?

____

25. Based on this, does the law of conservation of momentum hold in this case? Why or why not?

____

____

APPENDIX B: Conservation of Energy PhET Activity

The Conservation of Mechanical Energy

Objective

We will calculate the total mechanical energy in the system at different points by calculating the elastic potential energy and gravitational potential energy. Those results will be compared to determine if mechanical energy is conserved in an oscillating spring.

Materials

Computer with internet access

Pre-lab Questions

1. Define Elastic Potential Energy (EPE).

2. Define Gravitational Potential Energy (GPE).

3. Say a mass is hung from a spring and attached vertically to a ring stand (see diagram). If the mass is pulled down and released, it will oscillate vertically. When the mass is at its highest point (and momentarily at rest), its form of energy is ______________________.
   - **a.** Elastic Potential Energy
   - **b.** Gravitational Potential Energy
   - **c.** Kinetic Energy
   - **d.** Thermal Energy

4. At the lowest point (also momentarily at rest), the primary form of energy for the mass is _____________________________.
   - **a.** Elastic Potential Energy
   - **b.** Gravitational Potential Energy
   - **c.** Kinetic Energy
   - **d.** Thermal Energy

5. In addition to your answer to the previous question, which other form of energy is likely present (as long as the mass is not touching the ground)?
   - **a.** Elastic Potential Energy
   - **b.** Gravitational Potential Energy
   - **c.** Kinetic Energy
   - **d.** Thermal Energy

Procedure

1. Go to http://phet.colorado.edu
2. Click on the orange "Play with Sims" button near the center of the page.
3. Click on the Physics tab on the left of the page.
4. Open the Masses and Springs simulation. Click Run Now to get started.
5. Fill in the following table as you work.

Mass (kg)	**Force (N) (Hint: Determined by gravity)**	**Distance Spring Stretched (m)**	**Elastic Potential Energy (J)** $PE = \frac{1}{2}kx^2$

6. Choose the 50g mass and record it on the table. (Notice the units on the table.) Also calculate the force of gravity for that mass and include that on the table.
7. Place the mass on the spring and after the spring comes to rest, measure the distance that the spring stretched.
8. Repeat steps 4 and 5 for the 100g mass and the 250g mass.
9. Now use the three masses on which there are no labels. The masses of these are:
    a. Green Mass = 70g
    b. Gold Mass = 150g
    c. Red Mass = 300g
10. Using LoggerPro, graph Distance Spring Stretched vs. Force.
11. Graph a line of best fit and find its slope. This is called the spring constant, *k*.

    Spring constant, *k* = ____________________________

12. Calculate the Elastic Potential Energy for each mass using the *k* value found above. Note that *x* = Distance Spring Stretched (m) from Column #3 of the table. Add the values to your table.

13. Place the ruler so that its top edge is directly next to the top horizontal part of Spring #1. Measure the position of the spring with no weight added to it. Record its position below. This will be called Position #1.

    Position #1 = ____

14. Place a 250 g weight on the spring and let it come to rest. Measure this position and record it below. This position is called the *equilibrium point*. We will call it Position #3.

Position #3 = ____

15. Move the "friction" slider to "none".

16. Pull the weight down so that the spring stretches further. After releasing it, record the highest point that the mass reaches and its lowest point. It will be helpful to choose "1/4 time" or "1/16 time" from the options in the green box. You will likely need to move the ruler to find the lowest point, so be sure to do this carefully and accurately. The highest point will be Position #2 and the lowest point will be Position #4. Record these positions below.

Position #2 = ____

Position #4 = ____

17. Check your work by pulling the mass to position 2 and releasing. It should oscillate between positions 2 and 4.

18. Complete the table below. Repeat steps 10-13 with two other masses. Be sure to use two masses that you've already used and have calculated the spring constant *k* for.

Mass (kg)	**Position #1**	**Position #2**	**Position #3**	**Position #4**

19. Use the formula for Elastic Potential Energy to compute the energy from the spring. The formula is EPE = $(1/2)kx^2$, where k is the spring constant found earlier and x is the distance between Position #1 and Position #2. Enter these values into the table below.

20. Use the formula for Gravitational Potential Energy to compute the gravitational energy from the mass. The formula is GPE = mgh, where m is the object's mass, $g = 9.8$ m/s^2, and h = the height of the object. Because we will use Position #4 as the "zero" point for gravity, the h value in this case is Position #2 – Position #4. Enter these values into the table below.

21. Find the Total Energy at each position by adding the EPE to the GPE at that position. Include your values in the table below.

Mass (kg)	**EPE at Position #2**	**GPE at Position #2**	**Total Energy at Position #2**

22. Repeat the last three steps for Position #4. This time, the *x* value will be the distance from Position #1 to Position #4. Because Position #4 is the "zero" point for GPE, there is no GPE at Position #4 for any of the trials.

Mass (kg)	**EPE at Position #4**	**GPE at Position #4**	**Total Energy at Position #4**

23. As the mass falls from Position #2 to Position #4 it loses GPE but gains EPE. Calculate the gain in EPE from Position #2 to Position #4.

Change in EPE from Position #2 to Position #4 = ________________________________

24. As the mass rises from Position #4 to Position #2 it loses EPE but gains GPE. Calculate the gain in GPE from Position #4 to Position #2.

Change in GPE from Position #4 to Position #2 = ________________________________

25. According the Law of Conservation of Energy, the mass should retain its energy after the spring is launched. This means that the change in EPE (in step 23) should be equal to the change in GPE (in step 24). Find the difference between your results in the prior two steps.

Difference between step 23 and step 24 = ________________________________

26. Take this difference divided by the result in step 24, then multiply by 100 to find the percent difference in the Total Energy of the system.

Percent difference in Total Energy = ________________________________

27. Subtract the result in step 26 from 100. This is your percent difference.

Analysis

28. Describe the energy transfer taking place as the mass falls from Position #2 to Position #4.

29. What is true about the kinetic energy (KE) of the system at Positions 2 and 4? How do you know this?

30. The Law of Conservation of Energy tells us that no energy in the system is lost. Is this true for your experiment? How do you know?

31. Why is it much easier to use Positions 2 and 4 instead of Position #3 to calculate the total energy of the system?