Projectile Excel Simulation – Jason Hwang and Daniel DuBrow

Purpose
This activity introduces the use of computers to simulate a simple experiment using theory. In this way we begin to build the three way tie between experiment, theory and simulation. The activity also promotes the use of spreadsheets for analyzing and visualizing experimental data. For this particular activity we are emphasizing the use of Newton's equations of motions, however, the calculation and simulation itself may be changed to match different topics in science.

Overview
-Before the beginning of the actual activity, preferably giving the students an entire period to work on this, we hand out the worksheet to the students. The worksheet introduces the problem and poses that simulating the projectile motion will be the most effective way of testing. The worksheet also prompts the students to work out the algorithm to be used in the simulation and poses a few critical thinking questions for the students to think about before working on the actual simulation.

-At the beginning of the actual activity, we first prompt the students to come up with the parameters of the simulation and then are walked through an example of how to calculate the changes in velocity and distance using only forces. The formulation for this may be found in the example spreadsheet given to the teachers.
-For students that finish quicker than the time alloted, the worksheet poses possible additions to the simulation through the introduction of inserting a 'ground' effect and air resistance. However, adding these will require the use of additional excel functions.

(Note: we modeled our spreadsheet after a lesson created by Michael Fowler from the University of Virginia)
-At the beginning of the actual activity, we first prompt the students to come up with the parameters, or variables, of the simulation. They should list out: initial eight, initial velocity, initial velocity angle, timestep, gravitational constant, air resistance constant and mass. We ask them to box these to keep them separate like a 'control panel.
-Next, we ask which variables are in the problem, there should be: Time, x Velocity, y Velocity, x, y.
-We sometimes generated one or two columns for them to get started (usually time and x velocity), using increments. $(T(n) = T(n-1)+dt, Vx(n) = Vx(n-1))$. An example formulation may be found on the spreadsheet given to the teachers.
-We found that filling in the rest of the columns and graphing the results usually took 2 class periods (1.5 hrs).
-For the students that finish faster, we introduced the concept of using if else statements to generate a 'ground' in the simulation and using air resistance in the spreadsheet.

-The students should then use the resulting spreadsheet to answer some previously generated questions. We chose to ask for the minimum time to hit a specific distance given a maximum velocity.

Student Outcomes
1) Familiarization with excel
2) Use of equations of motion
3) Understanding time stepping
4) Using a simulation to generate data
5) Changing initial conditions to fit a problem

Applications of learning – The students apply their knowledge of Newton's mechanics in solving a novel problem with a method that few, if any, will have used before.

Communicating – The students are instructed to generate a graph clearly showing their results without the reader having to decipher their intent.

Using technology – The students learn to use excel to simulate the physics behind solving a real world problem introducing the use of computers as another approach.

Working on teams – We encouraged working together in groups and the students would give each other insight on how to do a particular trick in excel or a shortcut.

Making connections – In doing this activity, we hope to promote the use of computer simulations in attacking physics problems rather than just as a tool for visualizing the data.

Illinois state science standards met:

Apply scientific inquiry and scientific habits of mind 11A/13A/13Bl.I

How the scientists really work 13A/12A-F/13B.J

Gravitational factors 12D/11B/13A.H

Time

We found that the optimal amount of time for the activity was two class periods, preferably together. The project may be done in one class period, but requires much more teacher intervention to speed up the progress.

Level

This activity will be beneficial for students that have had precalculus and a basic understanding of Newton's laws in mechanics (sophomores and juniors) in physics class.

Materials and Tools

A computer lab with Microsoft Office (excel) installed. A white-board or blackboard is useful for keeping track of the variables the students come up with as well as showing a suggested organizational chart for the data. A projector attached to a computer proved to be useful in giving step by step instructions.

A pre-lab worksheet given the class period before the lab allows the students to begin formulating ideas on how they will accomplish the activity.

Preparation

The teacher needs to become familiar with possible algorithms to complete the calculation of the spreadsheet as well as constructing their own master spreadsheet (the students' versions will differ, but the concepts will be similar) in order to understand the pitfalls and tricks of the activity.

Prerequisites

While no activities are required as a prerequisite, introducing excel navigation and general use of spreadsheets will make this lesson run much smoother and quicker. Emphasis on naming cells, applying equations and organization of data is especially important.

Background

Students should be familiar with the equations of motion and how to apply them with small changes in time (gone over in more detail in the worksheet). Familiarity with excel and organizing scientific data will save time during the activity.

Teaching Notes

The students will work at different paces, be sure to go around the room to ensure that a student is not stuck on a particular step for too long. If the problem is related to a trick in excel rather than a physics concept, showing them the trick is fine. Some students will grasp the concept very quickly and finish much faster. Additional steps for these students are available on the detailed walk through. In the beginning, asking the students to identify the dependent and independent variables helps organize the students' thought processes. Encourage working together, especially because of the large range of computer skills in the class.

Assessment

-We chose to ask the students to find the minimum time (and associated angle and initial velocity) to hit a target on the ground at a distance D, given a maximum velocity. The students will be able to use their generated simulation to find an acceptable solution

-Correctly assembling the spreadsheet (was given as homework if the student did not finish in class) up to a certain point. We decided not to include air resistance/ground for this checkpoint. We provided a more detailed walk through for the students that needed more help. Surprisingly only a small minority decided to take the walk through, rather figuring the method out themselves.

-Filling out the worksheet and answering the 'additional questions' section

Additional Information

-Prior to this activity, we walked the students through analyzing the experimental data of another lab using excel which helped the students become more familiar with spreadsheets.

-While most of the students finished around the same time, there were a few (~3 or 4) that had done something similar to this exercise in the past and finished within 30 minutes of starting. These were the only ones that were able to insert air resistance/ground into the spreadsheet.

-Animation could be added to the spreadsheet through the use of macros, but we thought that this addition would be unrealistic as the time commitment to teach macros is fairly high.

-A computer lab with at least one computer per student is recommended, but groups may be formed for places with less computers

Benchmarks/Learning Goals

Importance/application of simulations in science
-Introduce to students the practical applications of using computer simulations to approach scientific problems.
-Simulations may be used to go from observations to provide an insight into the physical theory (use the observation to figure out which model is correct) or to go from theory to observations (use theory to predict an observation).
-Show the three way relationship between theory, observation and simulations.

Understanding the mechanics/use of simulations
-We want the students to understand how to best use the simulation provided to them to solve various problems. By varying the parameters, the students are able to gain an intuition into the physics in a different way than solving problems or reading the textbook may provide.
-Understanding how to balance between accuracy and computational resources. In this particular simulation, the size of the timestep scales inversely with the amount of time required for the computation.

Forces
-We want the students to understand the concept that forces lead to a change in acceleration, which in turn leads to a change in velocity and finally distance. By showing how we update each quantity, we hope that the students are able to better understand the physics and mathematics of forces.
-Being able to include multiple forces on a single object. By seeing how air resistance and gravity can effect a single object independently, we hope to improve the students' insight into projectile motion. We include an open ended question about which other forces may be included to better simulate the projectile.

Use of spreadsheets
-The students should gain a better grasp on how using spreadsheets may speed up calculations of data and also how to visualize the data more clearly through graphing.
-We also want to introduce the notion of naming variables as an introduction to programming, which places an importance on variable referencing.

	Beginning	Developing	Satisfactory	Exemplary
Importance/Application of simulations	The student fails to complete the main task and does not understand how the simulation uses physics to evolve the state.	The student completes the main task (find the trajectory that takes the shortest amount of time given a velocity) using the simulation and is able to provide physical reasoning as to why and derive using equations of motion.	The student is able to answer the critical thinking questions provided in the worksheet. (e.g. How would you adjust the simulation if you wanted to calculate projectiles on the moon? Answer: change the gravitational constant)	The student makes additional changes to the simulation (some are provided as bonus material); for example, adding in 'the ground'.
Understanding the mechanics of simulations	Student does not understand the differences between choosing different resolutions for the simulation.	Student chooses a timestep that is both accurate enough for the simulation and finishes in a reasonable amount of time.	The student chooses a resolution that is reasonable (not too high or too low) for the problem and also investigates the relation between computational time and accuracy.	Student is able to calculate the specific pros and cons to having different number of 'nodes' during the simulation, more specifically, the minimum number of nodes required for the accuracy desired.
Forces	The student inputs the physics incorrectly and has to rely on the detailed walk through guide.	The student is able to complete the calculations required without the walk through guide.	The student understands how the acceleration is dependent on the force calculation, the velocity on the acceleration and the change in distance on the velocity.	The student understands that in the simulation we are approximating the calculations and to what degree.
Use of spreadsheet	The student is not able to complete the spreadsheet.	The student is able to complete the spreadsheet but does not use variable naming or data graphing.	The student completes the spreadsheet using variable names and produces clear graphs of the data.	The student goes beyond the tools presented and is able to generate shortcuts/improvements to the UI.