DIY MODELING: A MODELING-SIMULATION COMPLEMENT TO CLASSROOM TECHNOLOGIES IN UNDERGRADUATE PHYSICS AND ENGINEERING COURSES

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Abstract: Prompted by Eric Mazur's 1997 book and his promotion of the practical classroom techniques of *peer instruction*, many physics and engineering classrooms have evolved into activity-based studios for student learning and assessment, and Physics Education Research (PER) has emerged as a research field at many universities. This philosophical change in the way teachers think about student learning has been accompanied by new classroom technologies that included video analysis techniques, student response cards (clickers), and a robust suite of sensors that bring classrooms and laboratories to life with the ease of plug-and-play data acquisition. PASCO Systems is one such sensor suite adopted at West Point in its introductory physics and math courses. In the context of studying a vertical spring-mass system, a motion sensor that uses the echo of ultrasonic sound off of the bottom of the mass is a reasonable tool to analyze the harmonic motion and its dampening characteristics. Unfortunately, the data does not match the models used in most introductory textbooks because these simplified models omit the torsion of the spring and constrain the problem to 2-D. We have measured the impact of this omission to contribute to systematic error, and the rotation of the mass and the 3-D motion are easily observed. To complement these classroom activities, we propose using *DIY-Modeling*, which is a 3-D modeling-simulation program that generates realistic, game-like graphics for student visualization and experimental testing. A consortium of math, physics, and engineering educators from nine universities collaborated with a commercial software developer, Tietronix, to produce *DIY-Modeling*. The purpose of this paper is to address how *DIY-Modeling* might bridge gaps in existing classroom technologies and to develop spring-mass curricular materials that might be more generically applied to other physical systems where introductory models require more sophisticated analysis through modeling and simulation.

Key words: modeling & simulation, educational technology

Introduction

Prompted by Eric Mazur's 1997 book and his promotion of the practical classroom techniques of *peer instruction*, many physics and engineering classrooms have evolved into activity-based studios for student learning and assessment, and Physics Education Research (PER) has emerged as a research field at many universities [1, 2]. This philosophical change in the way teachers think about student learning has been accompanied by new classroom technologies that included video analysis techniques, student response cards (clickers), and a robust suite of sensors that bring classrooms and laboratories to life with the ease of plug-and-play data acquisition. PASCO Systems is one such sensor suite adopted at West Point in its introductory physics and math courses. In the context of studying a vertical spring-mass system, a motion sensor that uses the echo of ultrasonic sound off of the bottom of the mass is a reasonable tool to analyze the harmonic motion and its dampening characteristics. Unfortunately, the data does not match the models used in most introductory textbooks because these simplified models omit the torsion of the spring and constrain the problem to 2-D. We have measured the impact of this omission to contribute to systematic error, and the rotation of the mass and the 3-D motion are easily observed. To complement these classroom activities, we propose using *DIY-Modeling,* which is a 3-D modeling-simulation program that generates realistic, game-like graphics for student visualization and experimental testing. A consortium of math, physics, and engineering educators from nine universities collaborated with a commercial software developer, Tietronix, to produce *DIY-Modeling* [3, 4]. The purpose of this paper is to address how *DIY-Modeling* might bridge gaps in existing classroom technologies and to develop spring-mass curricular materials that might be more generically applied to other physical systems where introductory models require more sophisticated analysis through modeling and simulation.

The vertical spring-mass system

Most introductory physics textbooks analyze the spring-mass system over several chapters dealing with force, energy, and oscillatory motion. The physical system is rich with many important concepts that allow educators to cycle through the building blocks of Hooke's Law, conservation of energy, and oscillatory motion under conditions with and without non-conservative force or energy loss mechanisms. So for example, students can examine a horizontal spring-mass system on which the mass moves back and forth along a nearly frictionless surface. It is relatively straight forward to model this as an exchange between kinetic energy (K) with spring potential energy (U_s) and even with some friction the model can enhanced with an exponential dampening term. What's true in this case, is that the mass in confined to move along a 1-D track and consequently the spring is unable to exert a torque to cause the mass to spin.

This constraint does not exist with a vertical spring-mass system in which one end of a spring is attached to a fixed point and a mass is attached to the spring's other end. Pulling the mass downward creates a dynamic that requires analysis of gravitational potential energy (U_G) and the possibility of 3-D motion and rotation of the mass due to the torque exerted when the spring coils change in length. In both the vertical and horizontal cases, the use of ultra-sonic motion sensors is commonly used by undergraduates in laboratories. The vertical case produces results that may not be consistent with what undergraduates study in their textbooks.

Motion sensor experiment

A *PASCO* ultrasonic motion sensor was used with a *Data Studio* computer interface [5]. The experimental set-up is shown in Figure 1. Distance measurements are from the sensor to the bottom of the hanging mass. The motion sensor was calibrated using a target 84 cm from its face, and it operated in the "wide angle" setting at 100 Hz. A 200-g mass was attached to a spring with a spring constant measured to be 2.75 N/m.

The sensor and a series of hanging masses (50-300 g) were used to measure the spring constant. The graph of distance to the hanging mass versus mass is linear, and its y-intercept represents the distance (d_0) to the bottom of the mass with the spring un-stretched. Figure 2 shows the results accounting for d_0 and using a regression analysis to determine the spring constant. The slope of this graph equals acceleration due to gravity (g) divided by k.

Data Studio is used to measure the time dependent distance (d) between the sensor face and the bottom of hanging mass. d_0-d provides the distance that the spring is stretched (x) and hence the spring potential energy ($U_S=kx^2/2$). Differentiating $d(t)$ provides the mass speed (v) and hence its kinetic energy ($K= mv^2/2$). The minimum value for $d(t)$ is used as the reference position (h=0) for the gravitational potential energy ($U_G=mgh$). Figure 3 shows these three energy terms and portrays the predictable differences in their phase and the exchange of energy between the three terms. At the mass lowest position, U_G is a minima, U_s is a maxima, and K is zero because the mass is momentarily brought to rest. At the highest position for the mass, U_G is a maxima, U_s is a minima, and K is zero because the mass is momentarily brought to rest. The mass is moving the fastest at center height (equilibrium position) and this is where K is the greatest.

Figure 4 shows the unexpected. In cases when all energy terms are accounted, the sum of these three energy terms should remain constant (when only conservative forces are acting) or should exponentially decay (when non-conservative forces are acting). The total energy is sinusoidal and exponentially decays which is explained by loss mechanism from non-conservative forces. The oscillation amplitude is approximately 0.02 J. The spikes in the data are instances where the sound wave from the motion sensor misses the hanging mass and reflects of the ceiling of the lab room.

Analysis

Below in Figure 5 is a closer look at the data shown in Figures 3 and 4. The scale permits a view of the exchange of the kinetic energy and the two potential energies considered to this point and a subtle view of the sinusoidal variation in the total energy. The peaks in the total energy occur when the hanging mass is at its highest position, and the valleys occur when the mass is at its lowest position. This can be explained with some consideration of the torsion potential energy related to the coiling and un-coiling the spring. Bear in mind that the spring potential energy is more sensitive to changes in height due to the square of this term.

At the lowest position of the mass, the spring is un-coiled and hence storing some potential energy in this system; without it, the mass would travel to a lower position and spring potential energy would be increased. This would in effect raise the valley in the total energy. As the mass moves upward, the spring is coiling resulting in the mass being slowed to rest at the higher position; without this, the mass would continue to a higher position and the spring potential energy would be decreased. This would in effect lower the peak in the total energy.

During the experiment, the rotation of the hanging mass is evident, but so is the movement of the mass outside the vertical plane. Like a conical pendulum, the hanging mass oscillates outside the vertical plane. The spring-mass system is placed into motion with an initial displacement of the mass downward or initial force to provide kinetic energy. Even with the best intensions, the mass is not held to 1-D motion. This pendulum motion provides another component of gravitational energy that was not included the initial model. This may contribute to the sinusoidal nature of the total energy seen in Figure 4, although the explanation is not so straight forward as with the torsion pendulum explanation. Unfortunately, the motion sensor cannot provide data on 3-D motion. There are efforts at West Point to use video analysis and shadow projections to evaluate the departure of the spring mass system from 1-D motion. This technique shows some promise although it is still being developed.

DIY Modeling

Modeling and simulation is not constrained by sensor limitations. The ultrasonic motion sensor measures only relative distance between the sensor face and the object surfaced used to reflect the sound and so cannot examine the spinning of the hanging mass and its motion outside the vertical plane. Graphics in the video gaming industry has helped to make educational modeling and simulation more realistic. This coupled with strong computational capabilities have made modeling and simulation a reasonable complement to the educational technologies found in university teaching labs.

DIYModeling was developed with this in mind. A consortium of math, physics, and engineering educators from nine universities collaborated with a commercial software developer, Tietronix, to produce *DIY-Modeling*. The development was supported with a NSF Grant and the program, curricular materials, and example simulations are available for free at a Appalachian State University host site, http://diymodeling.appstate.edu/ . The 2D simulations let your students see math and physics relationships and with DIYModeling you can:

- use pre-built simulations from our library
- adapt simulations to your own needs
- build new simulations from scratch

The centerpiece of the DIYModeling project is software, called **DIYModeling,** that enables students, faculty, and curriculum developers to produce game-quality, three-dimensional simulations without knowing computer programming or knowing how to use software like Blender or 3dsMax.

Building simulations requires understanding the underlying science and mathematics. For that reason, **DIYModeling** is particularly appropriate when you want your students to focus on the underlying science and mathematics. Nonetheless, because of time constraints you may want your students to use pre-built simulations or to make small modifications in pre-built simulations.

The spring mass system has been pre-built into DIYModeling. The simplicity of the model is striking. With just two equations defining a position and velocity vector, the math and physics package built into DIYModeling can do the rest and allow students to explore the behavior of this system. Below in Figure 6 is an example dialogue window in which the spring mass system is modeled for oscillatory motion in 3-D. Adding the rotation of the hanging mass is not much more difficult. Once the model is defined, the next step is to run the simulation. Simulations in DIYModeling can be developed to provide slider bars to change initial conditions or physical parameters of the system like mass and spring constant. The graphics allow for a change in perspective with the movement of a viewing camera. And all of the dynamics may be recorded here using a graphing tool to display the results. Figure 7 shows a screen shot for the spring-mass system.

Future work

In the context of the spring mass system, DIYModeling has the capability to demonstrate and characterize the complex dynamics observe in the system and to bridge gaps in sensor data. The 3-D motion and the rotation of the mass can be modeled. Right now what DIYModeling lacks is student assessment data. That's because there has been limited use with only eight collaborating universities, and even within those universities there are just a few faculty members to champion the embrace this new technology. There is some learning curve to its use, but the word is getting out about its value as educational modeling tool. At West Point, the Department of Mathematical Sciences and Department of Physics and Nuclear Engineering have faculty working together to develop DIYModeling Simulations and to prepare curricular material for use in our core introductory math, science, and engineering courses. The opportunities are rich since there are approximately 1,000 students in each of these courses.

References

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[3] TUES Research Grant, Funded by National Science Foundation, Division of Undergraduate Education, Transforming Undergraduate Education in Science, Grant TUES-0919264.

[4] DIYModeling Website, 30 Oct 2012< http://diymodeling.appstate.edu/>

[5] PASCO DataStudio software, 30 Oct 2012< http://www.pasco.com/family/datastudio/index.cfm>

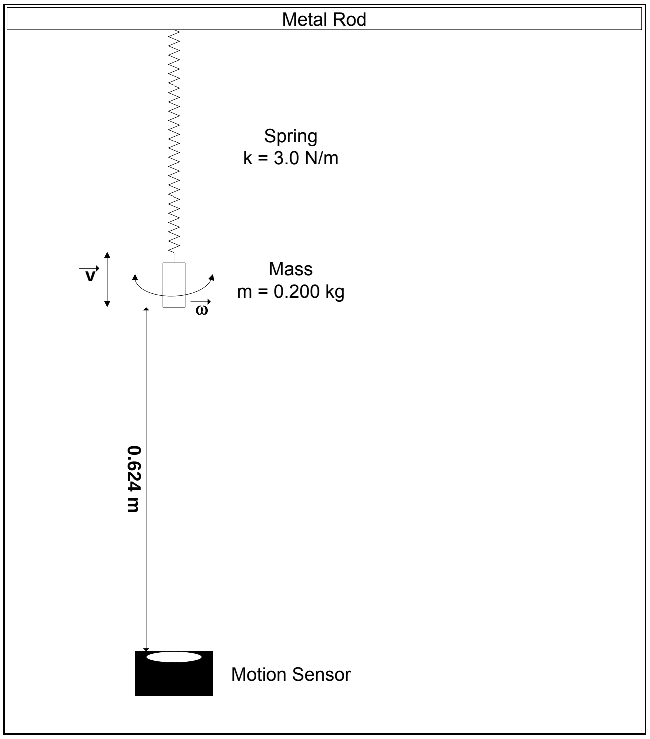


Figure 1. Experimental Set-up

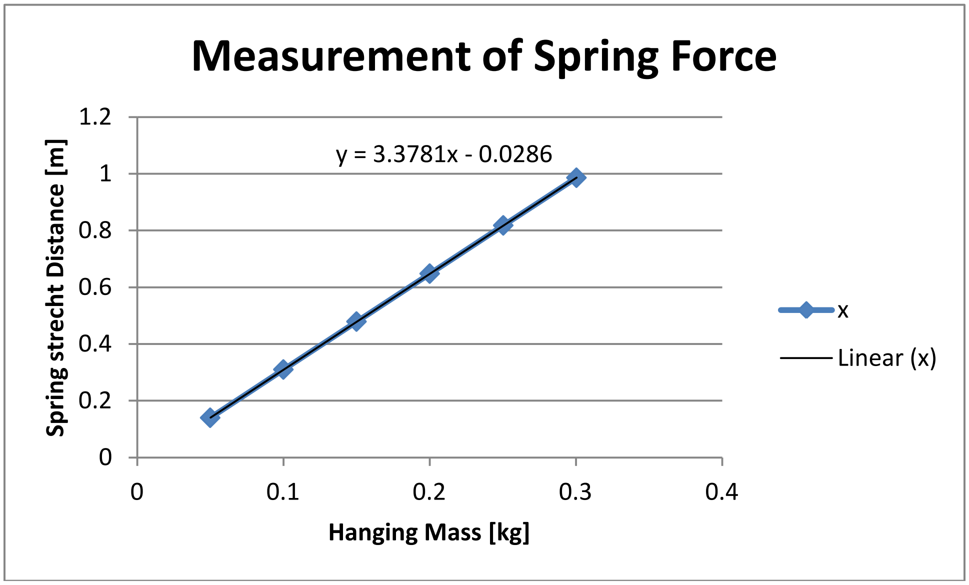


Figure 2. Linearization to determine spring constant

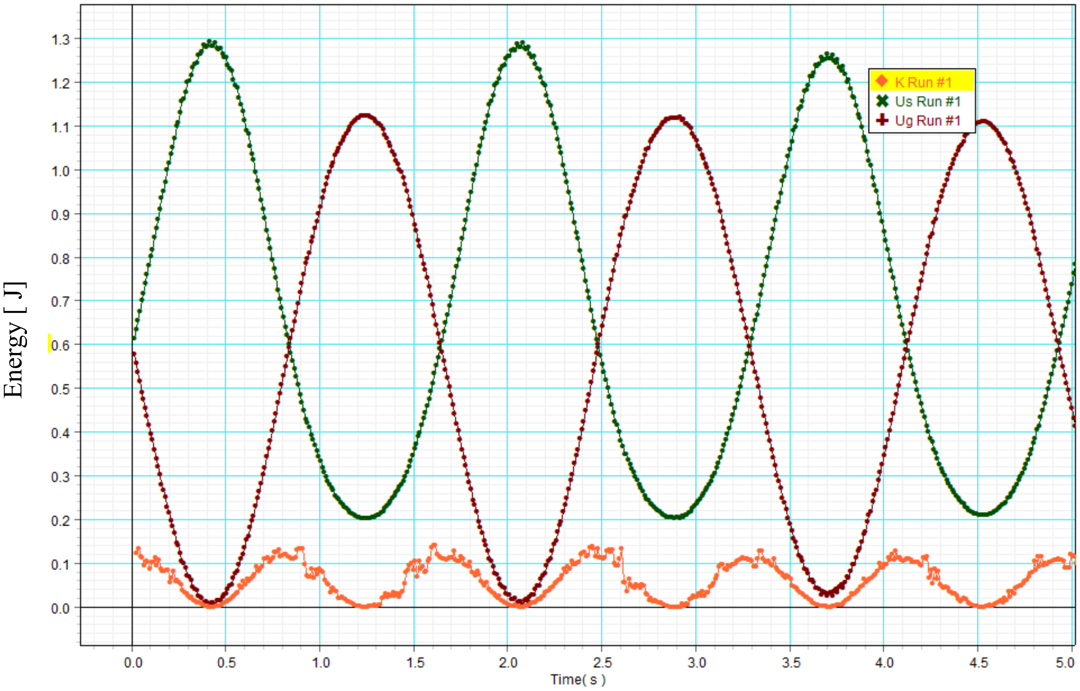


Figure 3. Harmonic motion with exchange of energy

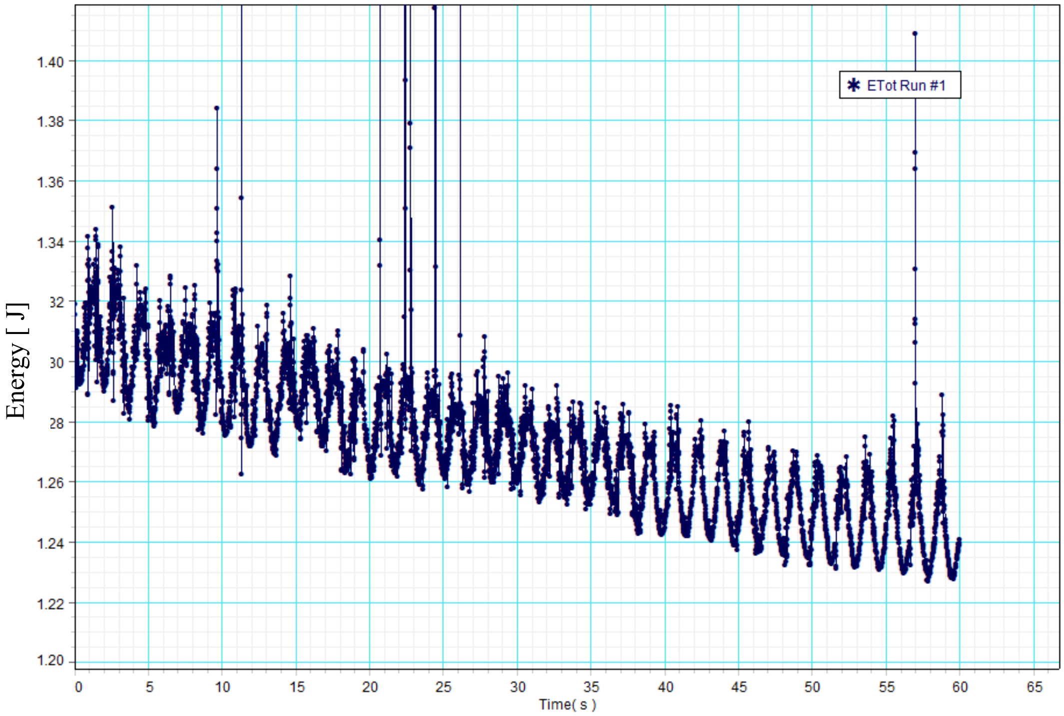


Figure 4. Total Energy

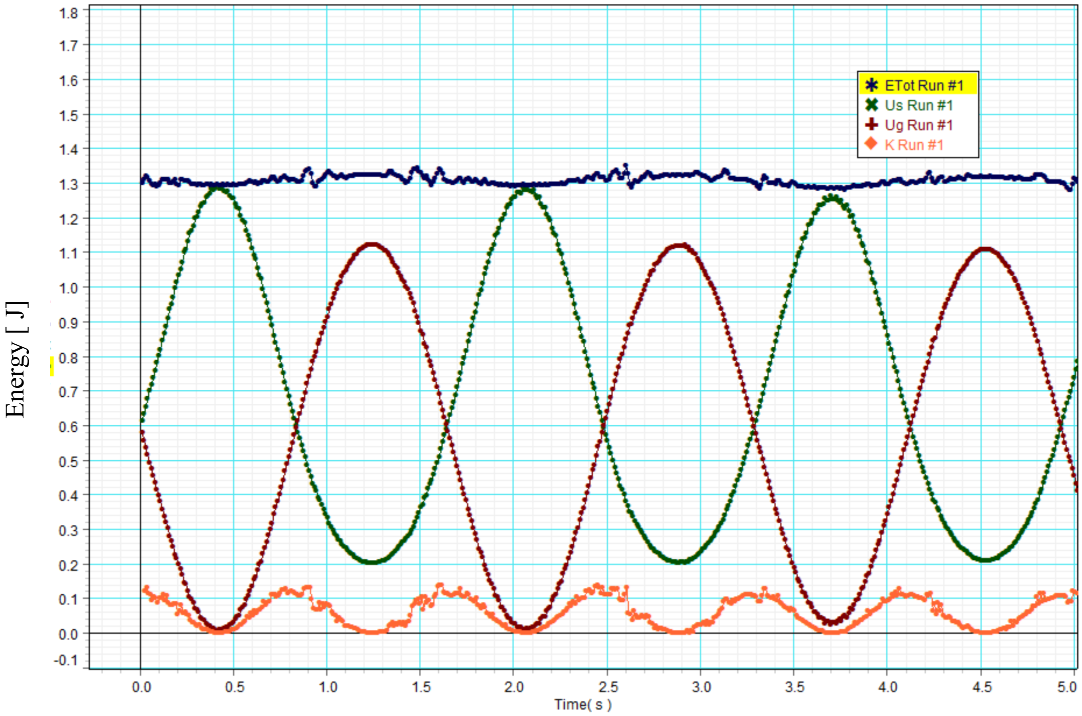
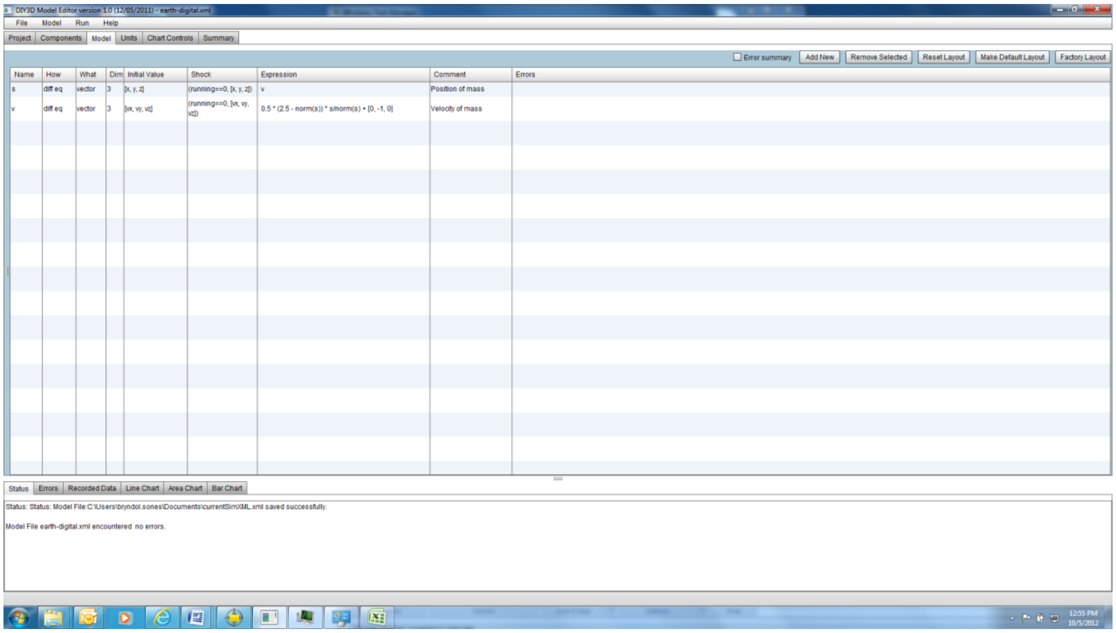


Figure 5. Total energy with kinetic and potential components



Name	How	What	Dim	Initial Value	Shock	Expression	Comment	Errors
s	diff eq	vector	3	[x, y, z]	(running==0, [x, y, z])	v	Position of mass	
v	diff eq	vector	3	[vx, vy, vz]	(running==0, [vx, vy, vz])	0.5 * (2.5 - norm(s)) * s/norm(s) + [0, -1, 0]	Velocity of mass	

```
Status: Status: Model File:C:\Users\bryndol.sones\Documents\currentSimXML.xml saved successfully.

Model File earth-digital.xml encountered  no errors.
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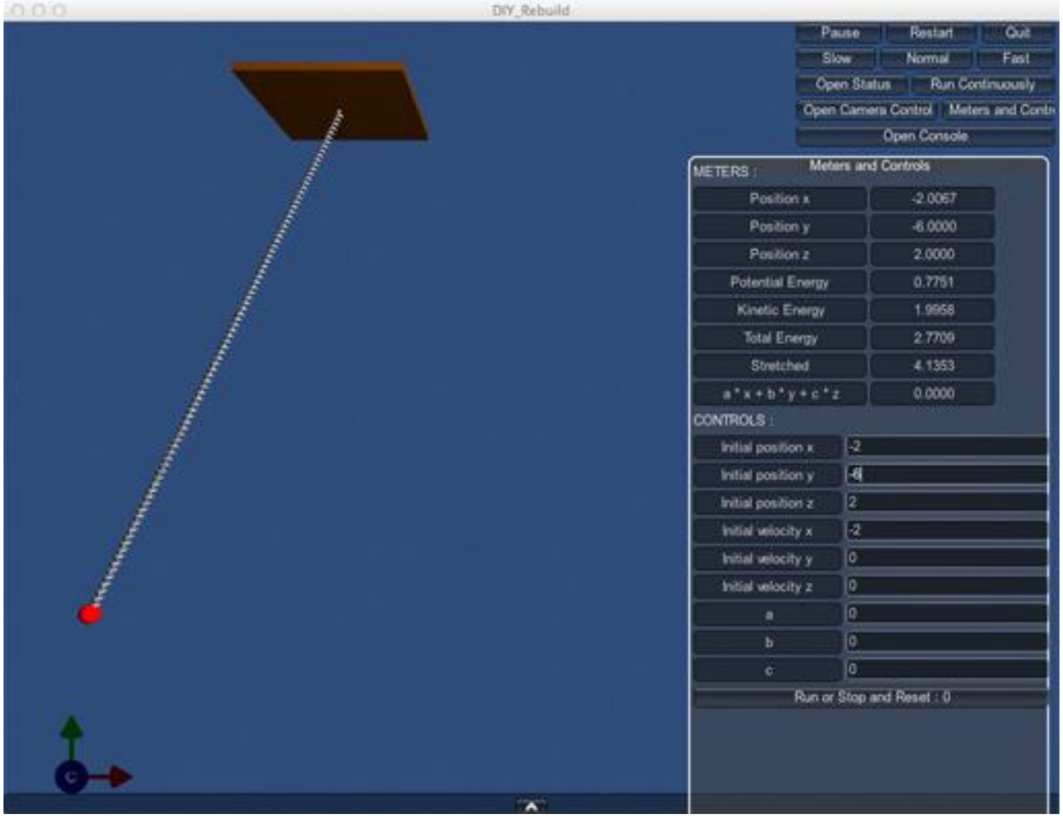
Figure 6. DIYModeling, vector definitions for spring-mass system



METERS :

Position x	-2.0067
Position y	-6.0000
Position z	2.0000
Potential Energy	0.7751
Kinetic Energy	1.9958
Total Energy	2.7709
Stretched	4.1353
a * x + b * y + c * z	0.0000

CONTROLS :

Initial position x	-2
Initial position y	-6
Initial position z	2
Initial velocity x	-2
Initial velocity y	0
Initial velocity z	0
a	0
b	0
c	0

Figure 7. DIYModeling, spring-mass simulation