CoreModels

Dynamics

Newton's First Two Laws of Motion

A Core Learning Goals Activity for Science and Mathematics

Summary: Students will investigate the first and second laws of motion in laboratory activities. After analyzing their results, they will use the discovered relationships to build a basic model which will serve as a template for other dynamics models.

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Dynamics
Table of Contents

Dynamics - Newton's Laws
Teacher Guide

Overview:
Students perform experiments to discover Newton's first and second laws of motion. They use graphing calculators or graphing packages to analyze the data from the experiment for Newton's second law. Then they construct a model which produces similar graphs. This model will be the basis of several other models.

Activities at a Glance:

Activity	Title	Materials	Estimated Time
1	Why Do Things Move?	Handout	20 min
2	Newton's First Law of Motion	Ring stands, string, masses	20 min
3	Newton's Second Law of Motion	Carts, tracks, masses, string, pulleys, CBLs, calculators, graphing package	60 min
4	Adding Force to the Acceleration Model	STELLA, computers	30 min

Prior Knowledge / Skills Required:
Students should have completed a unit in simple kinematics and understand the relationships between distance-time, velocity-time and acceleration-time graphs. They should have some experience with data analysis and the meaning of slopes for linear graphs as well as the use of power regression to determine the relationship for non-linear graphs. Students should have some experience with using CBLs and graphing calculators to collect data. They should also have built some simple kinematics models in STELLA.

Best Practices:
Following the 5 E's model, the first activity is meant as an engagement activity. It can also serve as a guide for final assessment. The students should be encouraged to answer the questions in this activity on their own. They will be concerned that they don't know the "right" answers so it is up to the instructor to assure them that this is only to discover what they know, it is not a test.

Activity 2 and 3 are exploration - explanation activities. These are suggested activities. There are many alternative activities available in the literature. Students should have the opportunity to explore these relationships in a lab situation and to work with data analysis in the case of the second law. At the completion of each activity, there should be plenty of

teacher-student discussion time to make sure that students have developed the correct relationships. It is especially important that teachers spend plenty of time discussing the effects of changing mass and changing force and how they are illustrated in Activity 3. Student misconceptions are strong in this area.

Finally, the students have a chance to augment their earlier kinematics model with the addition of mass and force to that model. Students are instructed to label the force as net force and also to add an applied and opposing force to the model. This again will require some teacher explanation as to the meaning of these terms.

Core Learning Goals:

Core Goal 1: Skills and Processes

3. Expectation: The student will carry out scientific investigations effectively and employ the instruments, systems of measurement and materials of science appropriately.

>   (1) The student will develop skills in using lab and field equipment to perform investigative techniques.

>   (3) The student will learn the use of new instruments and equipment by following instructions in a manual or from oral direction.

4. Expectation: The student will demonstrate that data analysis is a vital aspect of the process of scientific inquiry and communication.

>   (3) The student will determine the relationships between quantities and develop the mathematical model that describes these relationships.

>   (5) The student will choose appropriate summary statistics to describe tendencies revealed by data.

>   (6) The student will use spreadsheet, graphing and database programs and probeware on computers and/or graphing calculators.

>   (8) The student will use models and computer simulations to represent systems.

Core Goal 5: Concepts of Physics

1. Expectation: The student will know and apply the laws of mechanics to explain the behavior of the physical world.

>   (3) The student will analyze and explain how changes in an object's motion are described by Newton's Laws.

Dynamics - Newton's Laws
Teacher Guide

Introduction: In the previous unit, you learned about velocity and acceleration and how they are related to each other and the motion of an object. In this unit you will discover the source of motion. This is a concept that can be as confusing today as it was to ancient physicists.

Activity One: Why do things move?

Answer the following questions: **This is an opportunity for the teacher to see student misconceptions.**

Question 1.1: What makes things move?

Student answers will vary.

Question 1.2: Why do some things move at a constant velocity while other things accelerate?

Student answers will vary.

Question 1.3: How does a rocket work? Be sure to explain both how it works during take-off and once it is in space.

Student answers will vary.

Question 1.4: How do the brakes in a car work?

Student answers will vary.

Activity Two: Newton's First Law of Motion

Newton is credited with three laws of motion, sometimes known as the laws of dynamics. This short activity looks at the first law.

Procedure:

Tie a mass to a ring stand. Then tie a second string to the mass so that it hangs down. With one partner holding the ring stand, pull slowly on the bottom string until the mass comes loose.

Which string breaks? _____ **Should be the top string** _____

Reattach the broken string or use a new piece of string to replace it. This time pull quickly.

Which string breaks? _____ | **Should be the bottom string** | _____

Question 2.1: Explain your results:

> **This is a quick and simple illustration of the law of inertia. If the string is pulled slowly, the mass begins to move and it is the resistance of the ring stand which causes the upper string to break. If the string is pulled fast (yanked) the inertia of the hanging mass resists and the lower string breaks.**

Activity Three: Discovering Newton's Second Law

In this activity, we will examine Newton's Second Law of Motion closely.

Procedure:

For both parts, you will need a track, a "frictionless" cart, a wood block with a slot, a picket fence, a table pulley, a 50 g hooked weight and assorted weights to total 300 grams more, 1.5 m of string, paper clips, a CBL, a photogate with adaptor and a graphing calculator.

Set up the track so that the table pulley is at the end of the table and be sure the track is level. Thread the string through the hole on the cart and tie it to the cart. Tie the other end of string into a loop and hang it over the table pulley. Put the block on the cart, then put the picket fence into the slot on the block and tape it into position. Make sure the tape is only on the black portions of the picket fence. Load 300 g of weight on the cart. Gently tap the cart. It will probably roll a short distance and then stop. Attach paper clips to the loop of string until a gentle tap causes the cart to slowly roll down the track at nearly a constant velocity.

Now set up the photogate, CBL and calculator system so that the photogate is over the path of the cart-picket fence. The photogate should be close to the starting point for the cart but the picket fence should not pass through the photogate until the cart has started to roll.

Open the program menu by touching the PRGM key on the calculator. Select the program TIMER. At the opening screen, press ENTER. The next screen just reminds you to connect the photogate, so press ENTER.

From the next menu choose 2. CHECK GATE and follow instructions. Then choose 1. TIMING MODES, then 1. MOTION, then 1. SELECT DEVICE, then 1. VERNIER PICKET, then 2. COLLECT DATA.

This set-up and program is used by both parts below.

Part One: Constant Mass, Changing Force

With the cart pulled back and held, put the 50 gram hanging weight onto the paper clips at the loop end of the string. Put 200 grams on the cart.

When you are ready, press ENTER on the calculator and release the cart. Someone should be ready at the other end of the track to catch the cart. DO NOT let the carts bang into the end of the track or go over the edge of the table.

At this point, the program will allow you to view the d-t and v-t graphs. Observe and record your observations about the appearance of these graphs. Then choose the STATS option from the menu and copy down the first screen shown. Then use the REPEAT option.

Pull the cart back, move 50 grams from the cart and put it on the string (there is now 100 grams on the string and 150 grams on the cart). Make sure the calculator is ready to time, press ENTER and release the cart. Again observe and copy down the information from the first STATS screen.

Repeat the previous paragraph for 150 grams on the string with 100 grams on the cart, 200 grams on the string with 50 grams on the cart, and for 250 grams on the string and no extra mass on the cart.

Part Two: Constant Force, Changing Mass

Now pull the cart back, put 350 grams on the cart and 50 grams on the string. Again, ready the calculator, let the cart roll and observe the graphs and record the information on the first STATS screen.

For this experiment, the same 50 grams stays on the string, but 50 grams will be removed from the cart each time and laid aside. So REPEAT the experiment for 50 g on the string and 300 g on the cart, 50 g on the string and 250 g on the cart, etc, until there is no mass on the cart. There should be a total of eight runs. Finally, you will need to determine the mass of the cart-block-picket fence combination.

Put all the equipment away and organize your findings into two tables like the ones on the next page. The slope you copied from the first screen should be the acceleration of the cart. The total mass in the table for part two includes the mass of the cart-block-picket fence plus any mass on the cart.

Analyzing the Data:

Part One Data: **Part Two Data:**

Total Mass	Acceleration

Mass on string	Acceleration

Now create a graph of the data in each table.   For one table, the relationship is linear. Use linear regression and statistics and record that information. Sketch this graph.

   The other table will be non-linear. Sketch this graph. To determine the exact relationship between the variables, we use power regression. Use the power regression option to determine the power for the x variable.

Questions 3.1: Part A is titled Changing Force, constant mass.

   a.   What is the changing force?

   The mass hanging on the string.

   b.   How can we say that the mass is constant?

   The total mass (cart + masses) never changes, mass is just transferred from the cart to the string, but the same amount of mass is in motion all through the lab.

Question 3.2: Describe the relationship between force and acceleration as you determined it in part A.

   The relationship is linear.

Question 3.3: In part B, why is the mass considered to be changing and the force the same?

   Now the mass is removed from the system

Question 3.4: What relationship exists between mass and acceleration?

> **The relationship is an inverse one. As the mass increases, for the same force, then the acceleration decreases.**

Activity Four: Adding Force to the Acceleration Model

In this activity, you'll incorporate what you've learned about force to change an earlier model.

Open your previously created **acceleration - velocity** model. Add a net force and a mass converter and connect them to the acceleration converter.

Your diagram should look something like this:
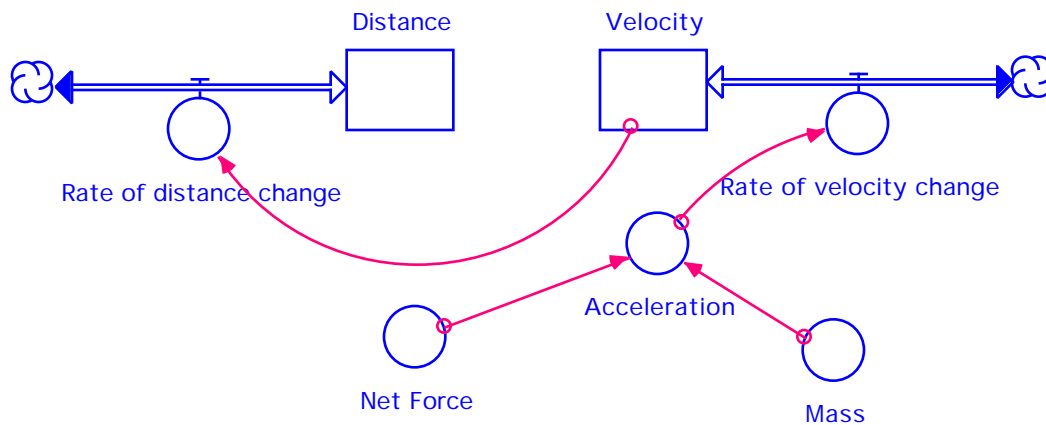
Set the initial velocity to 0 {m/s} and set the initial distance to 0 {m}. Double click on the acceleration converter and create the formula Net Force/Mass. Then double click on Net Force and set a value (try 10 {N}). Set mass to 2 {kg}.

Make sure you have a graph which shows Distance, Velocity and Acceleration vs. Time. Then run the model and observe the graph. **See Appendix A.**

Question 4.1:   Sketch the graphs below and explain why they appear the way they do.

> **Students should describe that the acceleration is a flat line, because it is constant through this experiment, the velocity is a line of positive slope because it is increasing at a steady rate equal to the acceleration. The distance graph is a half-parabola, since the velocity is changing (or the mass is accelerated) the object is covering greater and greater distances.**

Now we want to investigate the effect of changing force or mass. The quickest way to make several changes is to use sliders. Click on the up arrow at the left of the window to go to the map level. The red bar in the center of the icon strip is a slider. Drop a slider on the page, somewhere near the top. Next double-click on the slider and when the dialogue box appears, choose force. Then set the range for 5 to 25 and click OK.

Next, we need to create a graph. Double click on the graph icon and then on the graph. Click in the box labeled Comparative. Only one variable can be graphed this way. Put Distance in the right hand box.   Then find the upward pointing triangle which has New printed by it. Click on this to create a second graph (Page 2). Again, click comparative and now put Velocity in the right hand box. Repeat this process for a third page and Acceleration as a comparative graph and a fourth page and Force as a comparative graph. After clicking OK, move the graph so that the slider is visible, then use the "push pin" to anchor the graph on the page. Start with a force of 5 and run, then change the slider to 10 and run, etc. Look at the various graphs. **See Appendix B.**

Question 4.2: How does the change in force affect the acceleration and velocity?

> **As the force increases, the acceleration increases and the velocity graphs have steeper slopes (the final velocity is larger).**

Taking the Model Further

Question 4.3: Look at the effect of changing mass instead of force. All you need to do is change the slider to mass. You might want to change the Min to 1 and the Max to 5. Also, under Map, choose Restore Graphs. Now run, sketch and explain the results. **See Appendix C.**

> **As the mass increases, the acceleration decreases (for a constant force) and the velocity graphs have lower slopes (the final velocity is lower.)**

Question 4.4: Can we plot mass vs. acceleration? Yes! Get the graph dialogue box and click until you reach page 5. Now choose Comparative and Scatter. Choose mass first from the left box and click on the arrow to insert it next to the X. Then select acceleration and click it into the position next to Y. Run the model for each mass, sketch and explain the graph. **See Appendix D.**
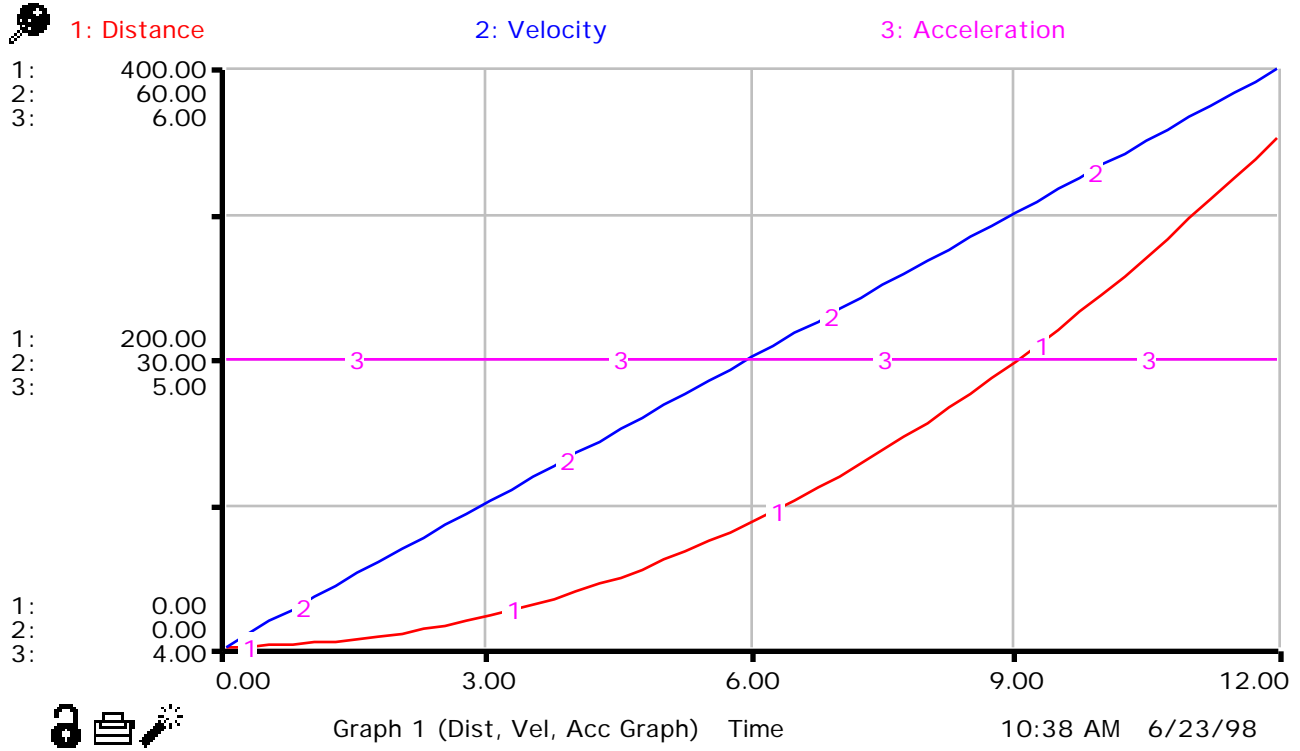
> **As the mass increases, the acceleration decreases. This graph is similar to the graph obtained in Part Two of Activity 3.**

Question 4.5: Return the model to a force vs. acceleration model and set up a force vs. acceleration graph. Change the slider back to a force slider. Run the model for various forces, sketch and explain the graph. **See Appendix E.**
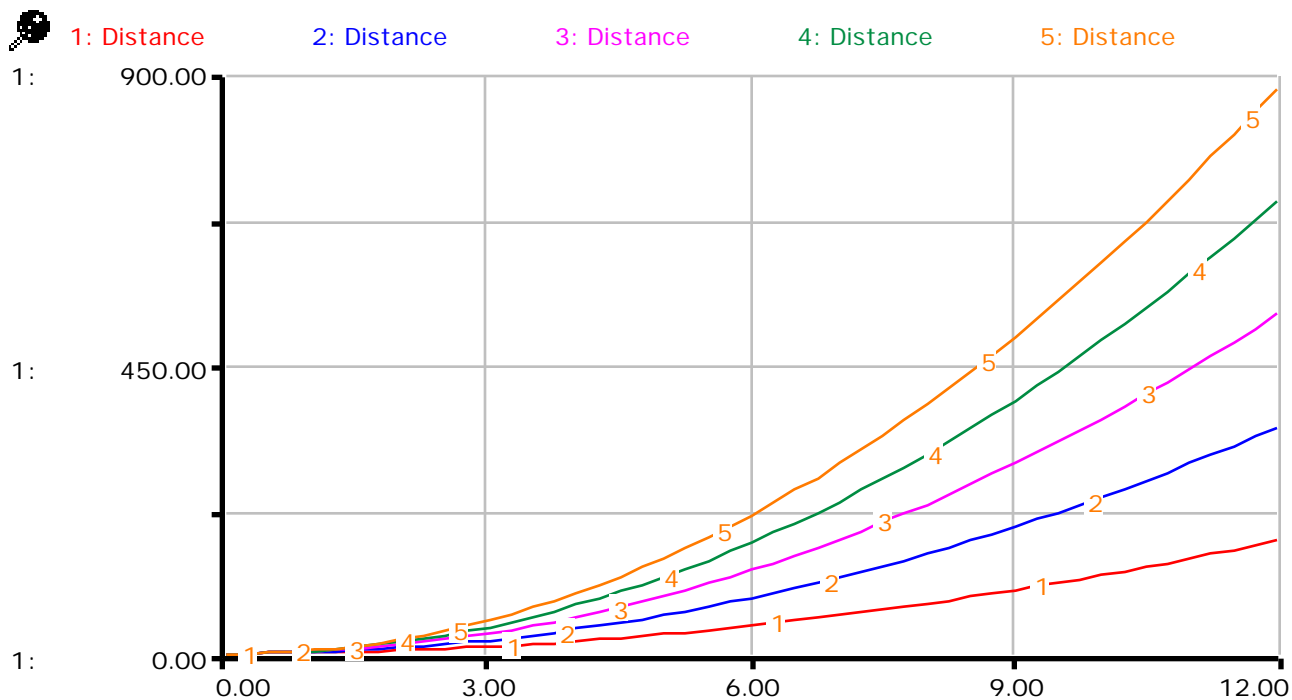
> **As the force increases, the acceleration increases. This graph is similar to the graph obtained in Part One of Activity 3.**

Getting Ready for Future Models: You're going to build several models which are variations of the basic force model, but each of these will have an applied and an opposing force. Add two converters to the force model, one for applied force and one for opposing. Connect them to the net force converter and change the net force converter to the equation applied force + opposing force. **SAVE** this model as **Force Template. See Appendix F.**
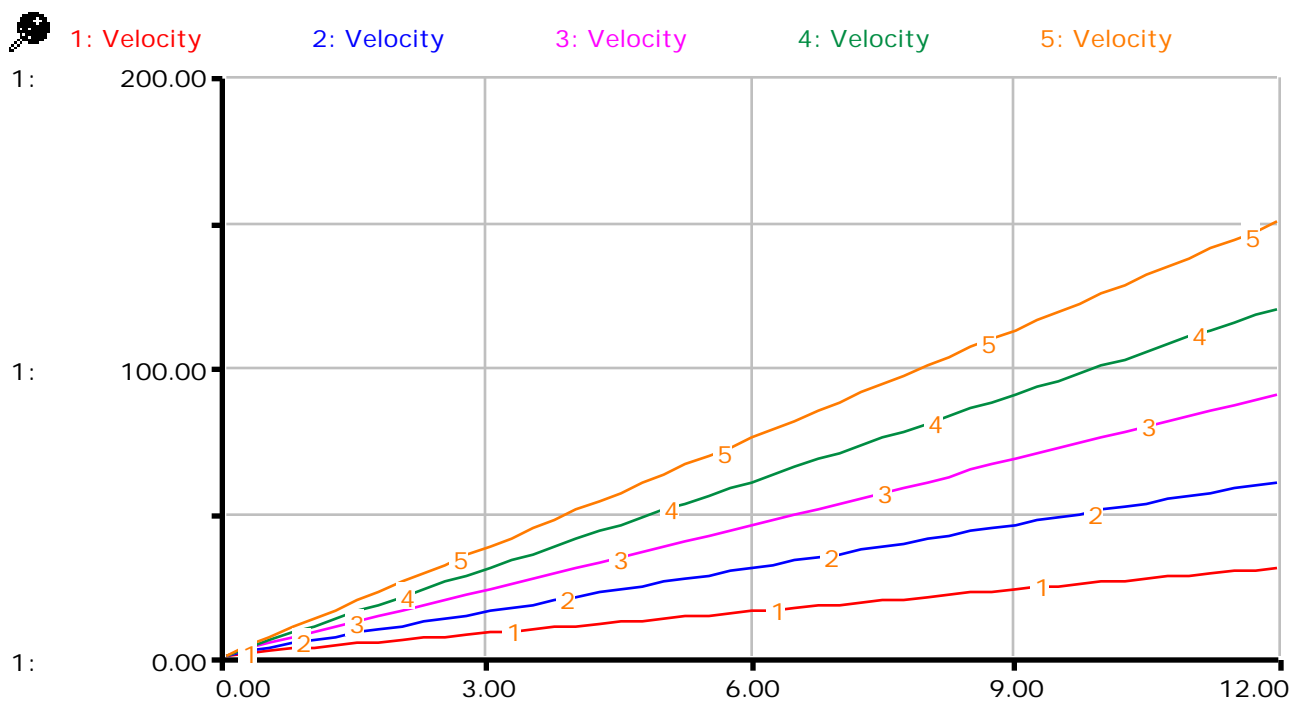
Dynamics
Appendix A

Graph 1 (Dist, Vel, Acc Graph)   Time

Dynamics
Appendix B

1: Distance   **2: Distance**   **3: Distance**   **4: Distance**   **5: Distance**

1:	900.00
1:	450.00
1:	0.00

0.00   3.00   6.00   9.00   12.00

Graph 1: p1 (Dist with force var Time   10:43 AM   6/23/98

1: Velocity   **2: Velocity**   **3: Velocity**   **4: Velocity**   **5: Velocity**

1:	200.00
1:	100.00
1:	0.00

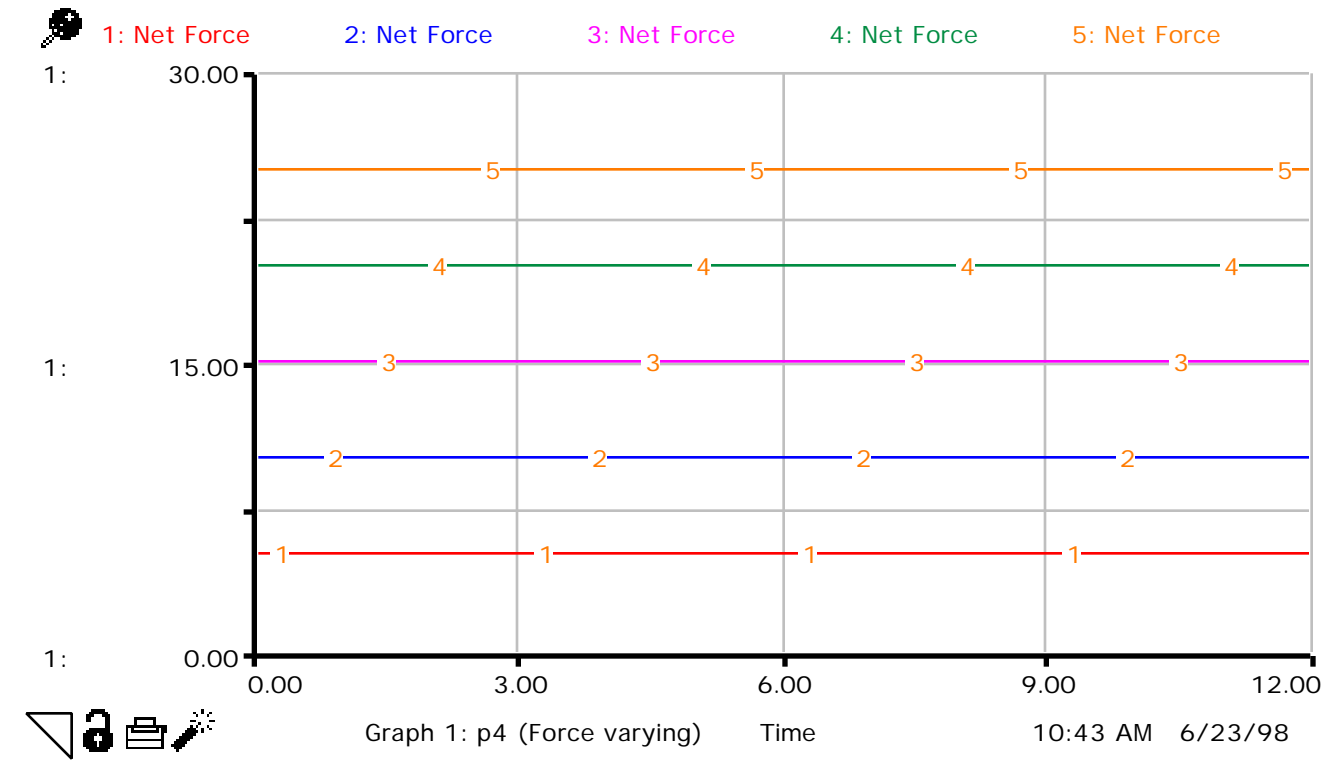0.00   3.00   6.00   9.00   12.00

Graph 1: p2 (Vel with force var Time   10:43 AM   6/23/98

A-2

Dynamics
Appendix B (cont.)

1: Acceleration   2: Acceleration   3: Acceleration   4: Acceleration   5: Acceleration

1:	20.00
1:	10.00
1:	0.00

0.00   3.00   6.00   9.00   12.00

Graph 1: p3 (Acc with force var Time   10:43 AM   6/23/98

1: Net Force   2: Net Force   3: Net Force   4: Net Force   5: Net Force

1:	30.00
1:	15.00
1:	0.00

0.00   3.00   6.00   9.00   12.00

Graph 1: p4 (Force varying)   Time   10:43 AM   6/23/98
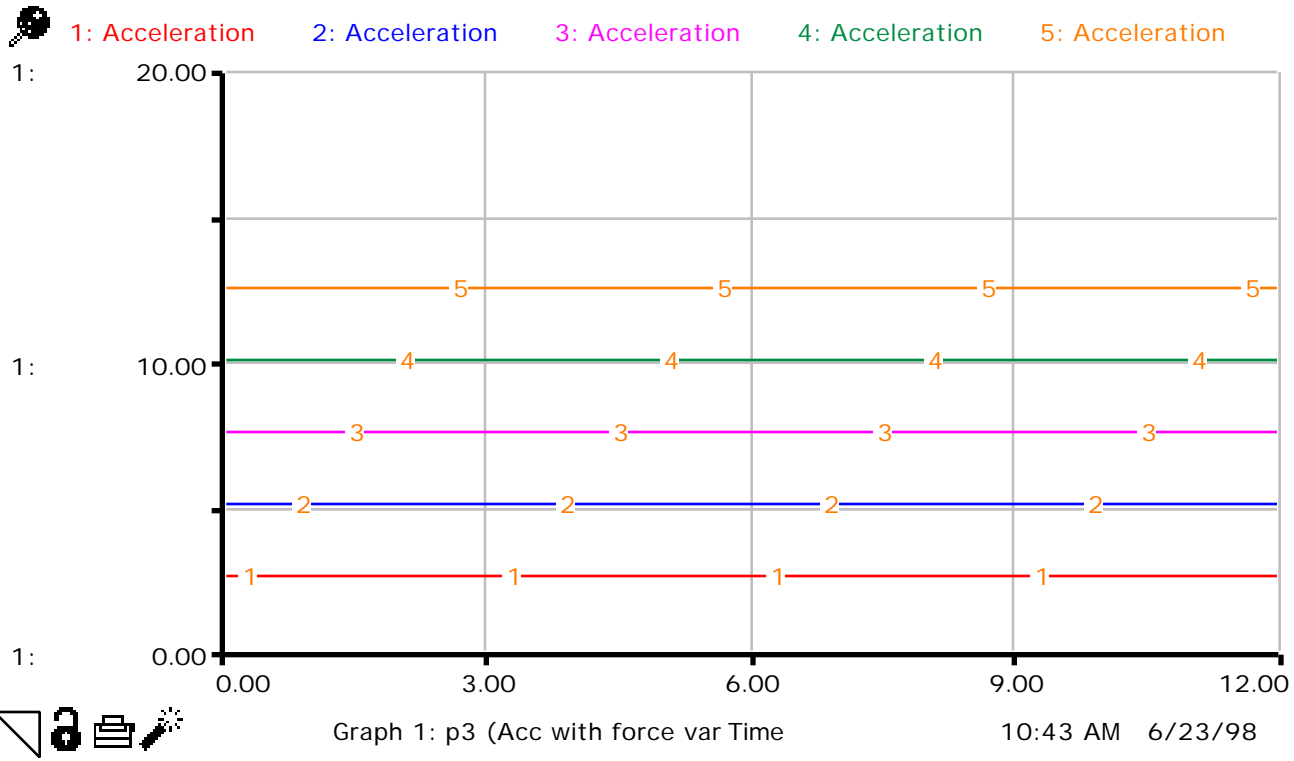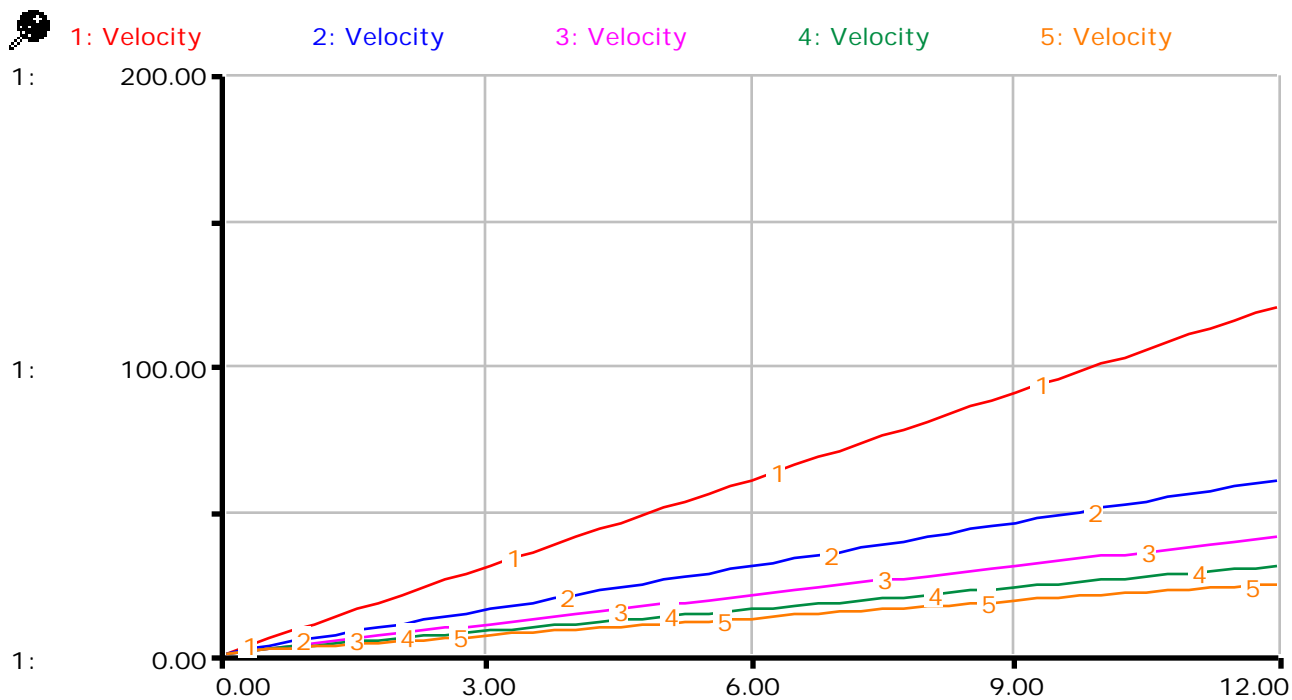
Dynamics
Appendix C
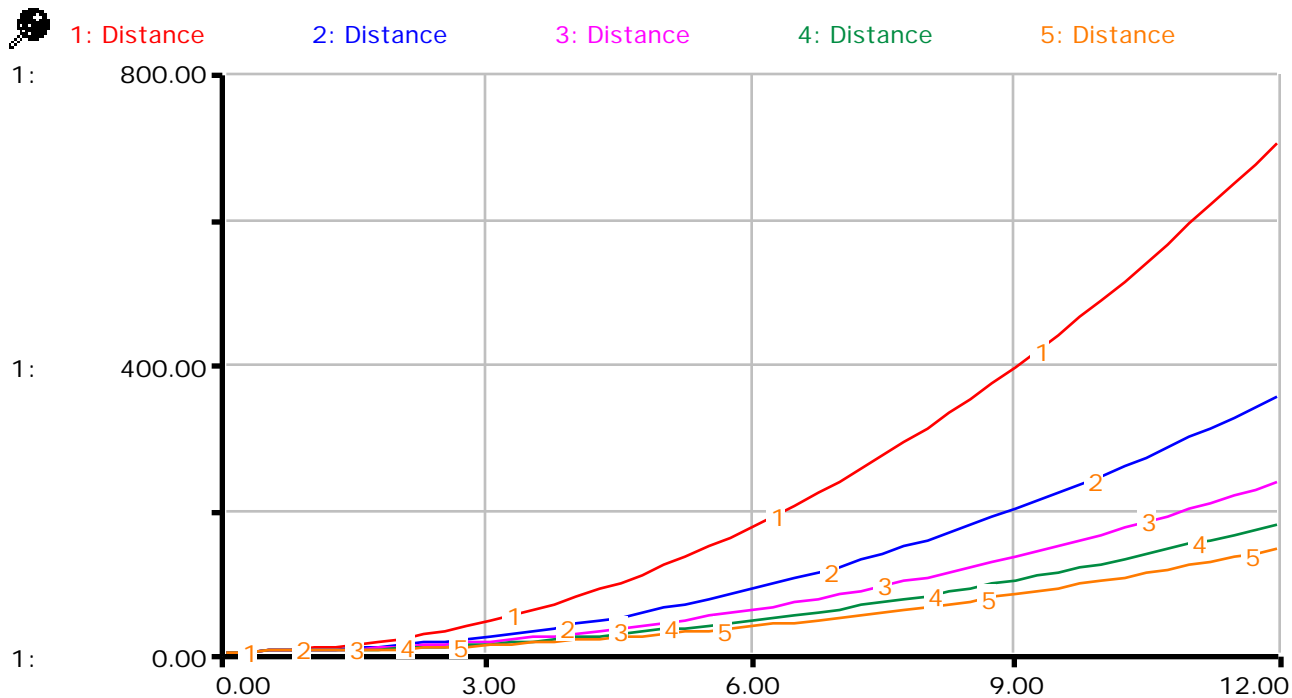
Graph 1: p1 (Dist with mass var Time   10:58 AM   6/23/98

Graph 1: p2 (Vel with mass varyTime   10:58 AM   6/23/98

A-4

1: Acceleration   2: Acceleration   3: Acceleration   4: Acceleration   5: Acceleration

Graph 1: p3 (Acc with mass var Time   10:58 AM   6/23/98

1: Mass   2: Mass   3: Mass   4: Mass   5: Mass

Graph 1: p4 (Mass varying)   Time   10:58 AM   6/23/98
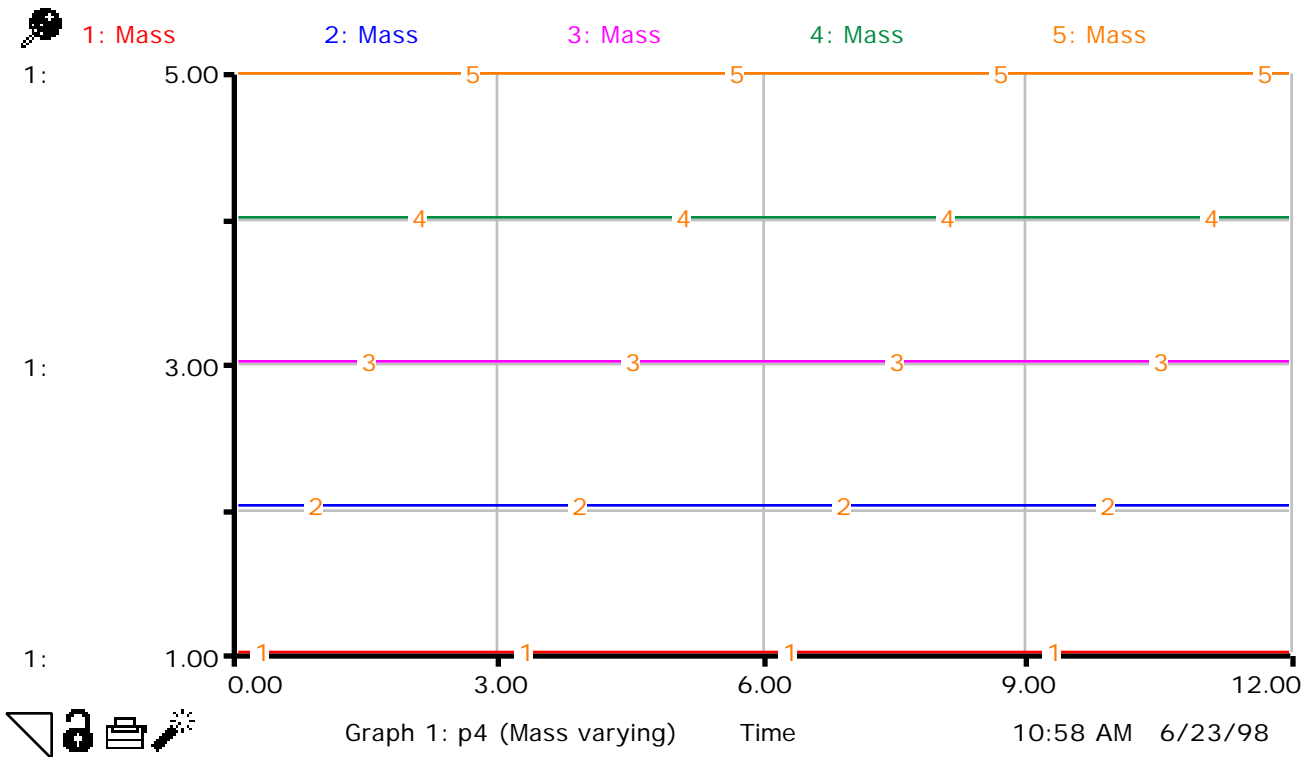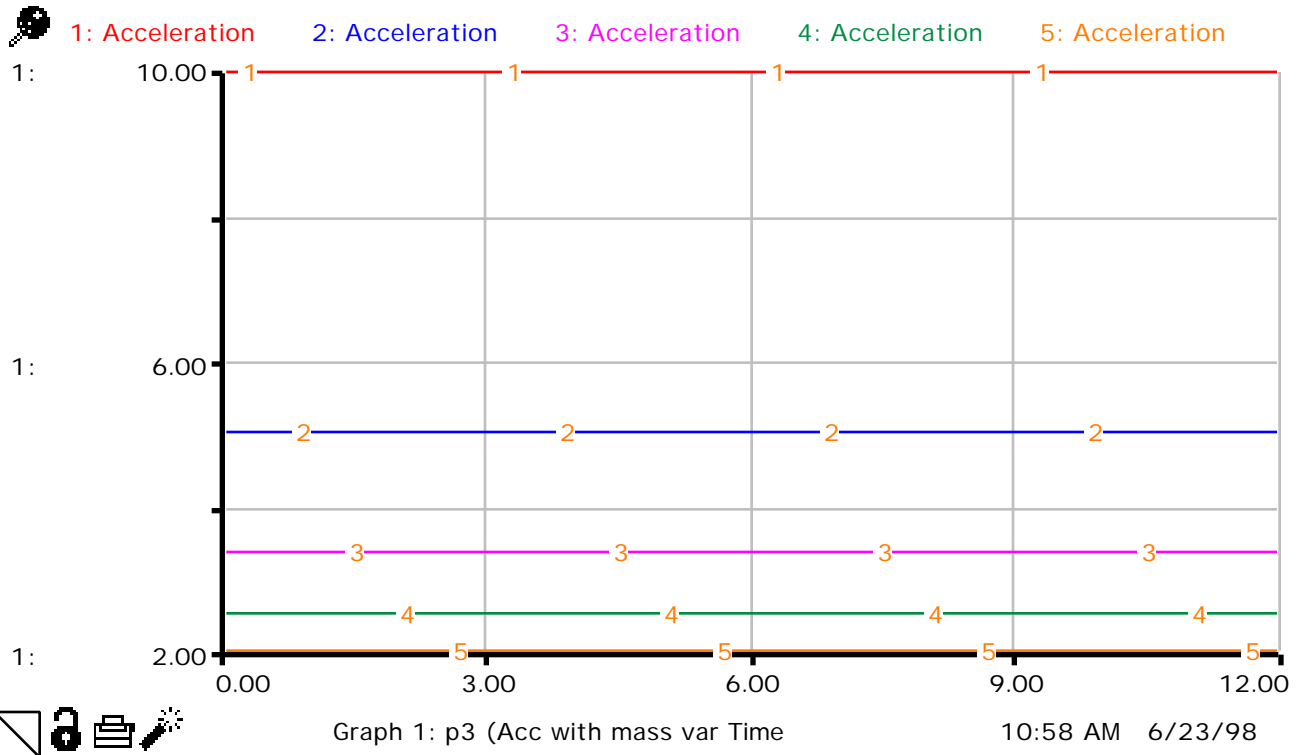
Dynamics
Appendix D

1-5: Mass v. Acceleration
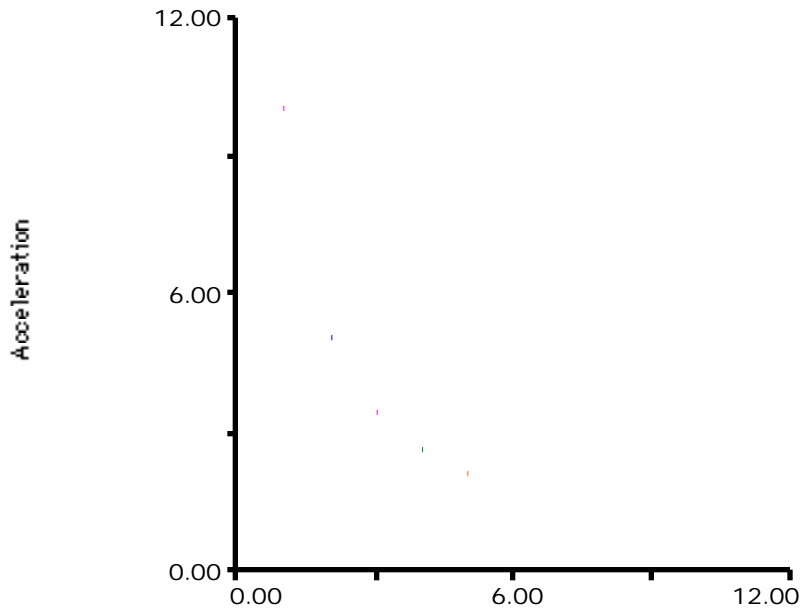
Graph 1: p2 (Untitled)   Mass   10:10 PM   6/30/98

1-5: Net Force v. Acceleration

Acceleration

10.00

5.00

0.00

0.00   5.00   10.00
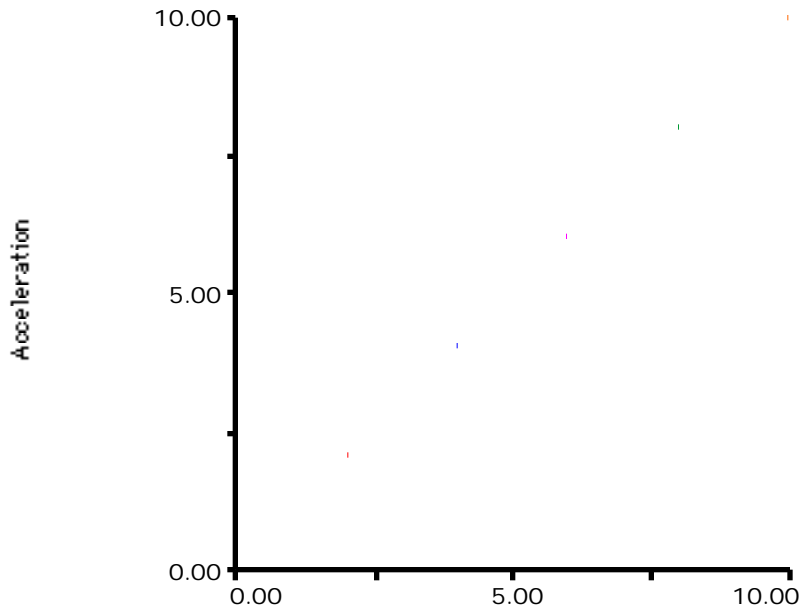
Graph 1: p2 (Untitled) Net Force   10:08 PM   6/30/98

Distance

rate of distance change

Velocity

Rate of velocity change

Acceleration

Net Force

Mass

?

?

applied force

opposing force