DYNAMIC MODELS
FOR
LEARNING AND EXPLORATION
IN
PHYSICS

THE VERTICAL THROW

BY

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Dynamic Models for Learning and Exploration in Physics is a collection of interactive computer models intended for use in introductory physics programs. Each model clarifies fundamental physics concepts and encourages exploration by simulating the dynamic behavior of carefully selected systems.

These models have been developed using STELLA II v. 2.2.2 software[1] and contain

- structural diagrams that identify essential system components and their interrelationships.
- equations needed to define the quantitative behavior of each component and its impact on the entire system.
- animated, graphical, and tabular representations of system behavior with interpretive material.
- suggestions for instruction and for enrichment activities.

They are unique in their ability to enhance student understanding and appreciation of chemical systems. Features which contribute to this uniqueness include

- spatial relationships of system components that will have appeal for students who find it difficult to contemplate systems that they cannot observe directly or for whom normal algebraic expressions are threatening or confusing.
- quantitative relationships that are clearly defined and are accompanied by documentation intended to facilitate fundamental understanding and to encourage manipulation of variables.
- dynamic simulations of the behavior of all parameters that may be selected individually or in combination and viewed graphically or in tabular format as desired by the learner.

The intuitive qualities of STELLA II are truly empowering and provide a platform for learner–directed learning that not only effectively generates insight and mastery, but is also grand fun! Although you may choose to have your students simply view and interpret the behavior generated by these models, you will likely encounter an irresistible urge to modify and explore the models further. This activity should always be encouraged. Of course, backup the models and graphs first!

Computer simulations make it no longer necessary to rely solely upon discrete, initial and final state observations and calculations to generate understanding. However, they must never be implemented as a substitute for direct observations of physical systems in the laboratory. Such experiences offer excitement, relevance, insights, and skills unattainable by other means.

Use these models as part of a balanced program to provide a dynamic introduction to physics that promises to reach many who might otherwise find it too abstract, elusive and, therefore, perhaps uninteresting. Then share your experiences and those of your students with others by communicating them to the author directly or through the Creative Learning Exchange.[2]

[1] High Performance Systems, Inc., 45 Lyme Rd., Hanover, NH 03755
[2] Creative Learning Exchange, 1 Keefe Rd., Acton, MA 01720

THE VERTICAL THROW

(Designed for use with Conceptual Physics, Chapter 2)

STELLA II modeling activities lend themselves to Hewitt's instructional approach by enhancing the conceptual framework of physics without belaboring the mathematics. The following exercise, intended for use when first introducing the concepts of motion, illustrates the behavior of a ball thrown upward with an initial velocity of 30 m/s. The parameters followed are speed, velocity, change in position, and acceleration. The flight dynamics are simulated for the moon, earth, and Jupiter.

PART I - STELLA II MODEL

This model can be constructed by students who are not only beginning their first physics course, but who are also new to the use of STELLA II.

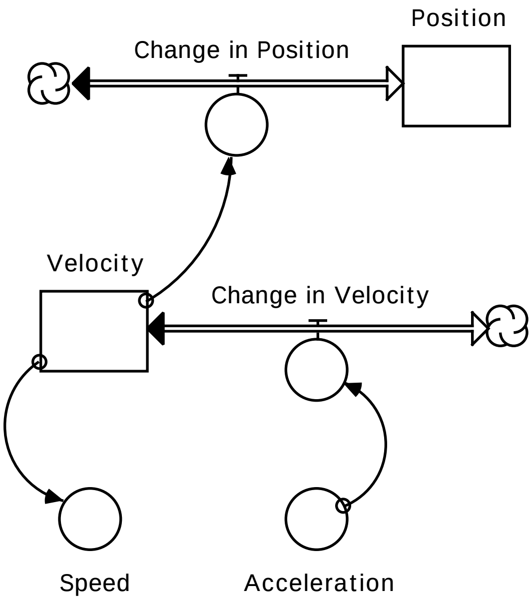

Figure 1. STELLA II model for a ball toss.

Most students have little difficulty comprehending that acceleration produces a change in velocity which, in turn produces a change in an object's position. This is the message inherent in Figure 1 and it is all students need to understand as they create the model. The mathematical operations are buried within the software.

Speed is calculated 'on the side' to enhance student awareness that speed and velocity are different and to enable a comparison of these two values during the simulation. As the absence of a connector leading from speed to any other component of the model shows, the speed has no impact on the simulation.

PART II - EQUATIONS

The equations for the simulation are given below. Students need only insert the following values (italicized in the expressions that follow):

- the initial position
- the initial velocity of the ball
- the acceleration constant
- the conversion for speed

Position(t) = Position(t - dt) + (Change_in_Position) * dt
INIT Position = ***0***
DOCUMENT: This indicates that the toss is starting at 'ground level'.

Change_in_Position = Velocity
Velocity(t) = Velocity(t - dt) + (- Change_in_Velocity) * dt
INIT Velocity = ***30***
DOCUMENT: This is set at 30 m/s (see Fig. 2-6, p. 18, of Conceptual Physics).

Change_in_Velocity = Acceleration
Acceleration = ***-10***
DOCUMENT: This is the earth's gravitational acceleration rounded to -10 m/s^2 (to be consistent with the value used in Conceptual Physics).

Speed = ***ABS(Velocity)***
DOCUMENT: The built–in function for absolute value is used to convert velocity to speed.

Before simulating, the following items need to be completed.

- Open 'Time Specs' and select the Runge-Kutta-4 integration method, a run-time of 6, a DT of 0.25 or less to generate a smooth curve, and specify the time units as seconds.

- Create graphs and tables to track parameters you wish to follow. These may be defined separately or in any grouping that you feel will be effective.

- Define axes as follows (for earth simulation):

  Velocity and speed (-30 to 30)
  Distance (0-50)
  Acceleration (auto–scale)

PART III - SIMULATION RESULTS: Earth Environment

Figure 2 is a simultaneous plot of the ball speed, velocity, and position under the earth's constant gravitational pull. For beginning students, the parameters should first be viewed independently on separate graphs and then collectively on one graph. This will avoid overwhelming them at first and will allow them to study the behavior of each parameter more carefully. The simultaneous plot shown below helps the student to acquire a more thorough sense of the system dynamics and is 'must' viewing before completing this exercise.

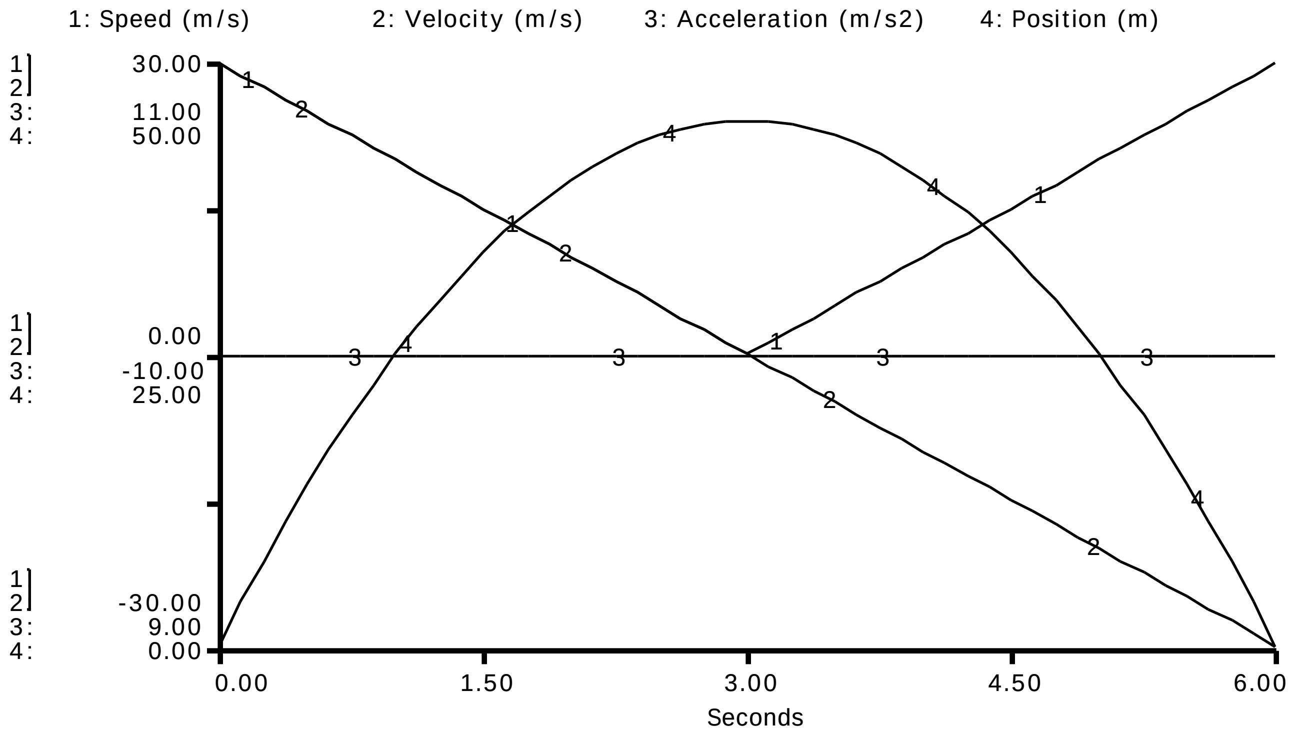

Figure 2. Simulation results for earth environment

The following behaviors are illustrated in Figure 2.

- The ball travels 45 m upward and then returns to the ground.
- The speed starts at 30 m/s, decreases to 0 m/s at the apex of the flight, and then increases to 30 m/s upon returning to the ground.
- The velocity starts at +30 m/s, decreases to 0 m/s at the flight apex, and then increases to -30 m/s at ground level. (The plot nicely accentuates the difference between speed and velocity.)
- The acceleration remains constant at -10 m/s^2 throughout the flight. (This is a difficult concept for many students. In fact, it's probable that many who express it accurately still find it difficult to believe. The simulation should help to reduce this doubt.)

Figure 3 is a scatter plot that effectively illustrates the amount of distance covered per unit time as the ball accelerates upward and downward.

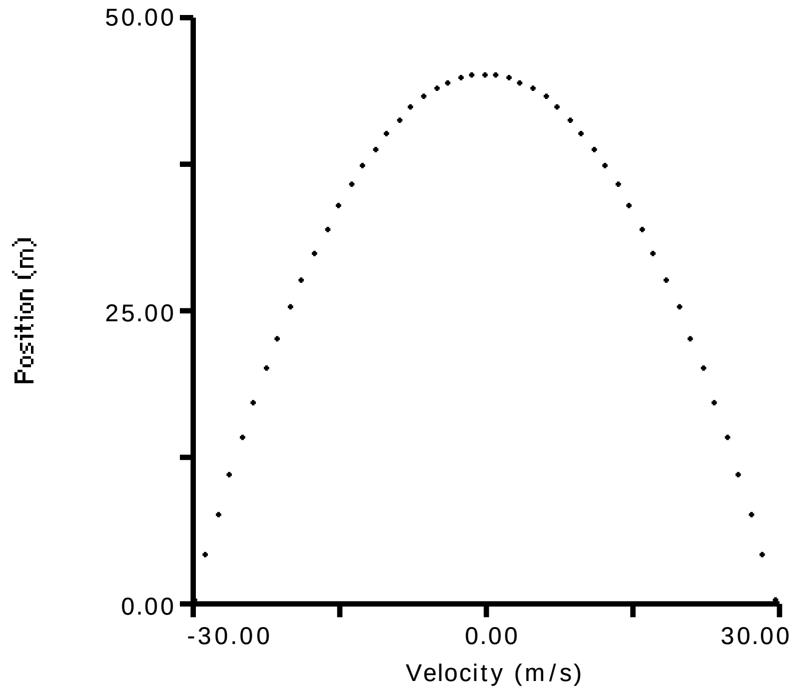

Figure 3. Change in position relative to change in velocity as the ball completes its flight.

The graphical outputs may be accompanied by data tables. Table 1 below includes the data used to generate the graphs for the initial earth simulations.

Table 1. Data for initial ball toss simulation on the earth.

Time (s)	Speed (m/s)	Velocity (m/s)	Position (m)	Acceleration (m/s^2)
0	30	30	0	-10
1	20	20	25	-10
2	10	10	40	-10
3	0	0	45	-10
4	10	-10	40	-10
5	20	-20	25	-10
7	30	-30	0	-10

Relationships such as the constancy of acceleration throughout the flight, the apical velocity, and final velocity are clearly presented in this table. The data may also be used for such activities as deriving or illlustrating the quantitative expressions, $v_f = v_o + at$, $d = (\frac{v_f+v_o}{2})t$, $d = v_o t + \frac{1}{2} at^2$, and $v_f^2 = v_o^2 + 2ad$. (Note: The model and its simulation enables students to develop these relationships conceptually without becoming overwhelmed by the mathematics.)

PART IV - SIMULATION RESULTS: Moon, Earth, Jupiter Comparison

Comparative studies of the flight behaviors that would be observed on other bodies such as the moon and Jupiter can be produced by using the sensitivity–run feature of STELLA II. To do this, open 'Sensitivity Specs', select acceleration and define the gravitational constants you wish to use. (Encourage students to research the constants for different bodies and to use these values for their simulations.) Then define graphs and tables for the parameters you want to view and be sure you turn on the comparative function of each graph and table.

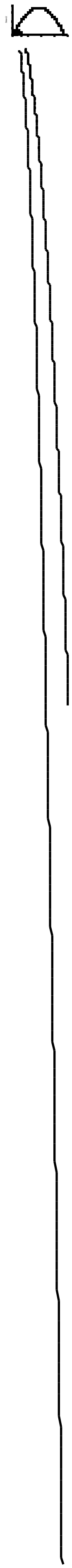

Figure 4 illustrates the change in position over time for the ball thrown directly upward at an initial velocity of 30 m/s on the moon, earth, and Jupiter. It confirms not only the differences in height that most students expect, but also illustrates the flight duration. Some students might be fascinated by the fact that on Jupiter they probably could not move quickly enough to avoid the falling ball which would then hit them with the same speed they gave it initially. It's also interesting to note that the ball would remain in flight for nearly 40 seconds on the moon!

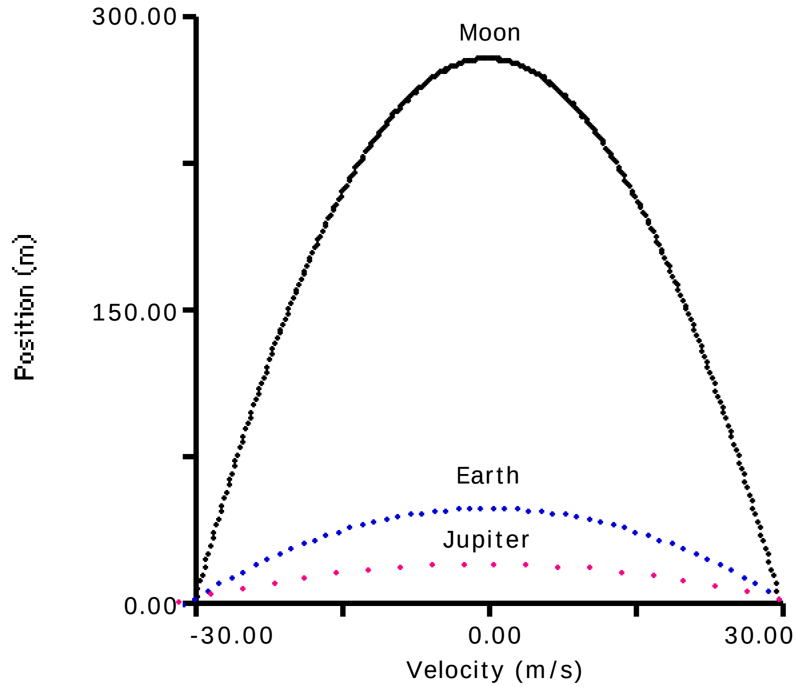

Figure 5. Change in position relative to velocity for moon, earth, and Jupiter flights.

Figure 5 is a scatter plot similar to that of Figure 3. It illustrates the amount of distance covered per unit time as the ball accelerates upward and downward on the moon, earth, and Jupiter.

Table 2 below provides the data generated for the comparative study of the changes in position of the ball relative to time as it is tossed on the moon, earth, and Jupiter, respectively. It can be seen that the ball is still climbing rapidly on the moon and is well into its fall on Jupiter when it is just at its apex on the earth flight. If able, the ball would fall about 13 miles on Jupiter and 4.3 miles on the earth during the time it takes for the full flight on the moon!

Table 2. Data for the comparative study of the change in position on moon, earth, and Jupiter

Time (s)	Moon Flight (m)	Earth Flight (m)	Jupiter Flight (m)
0	0	0	0
1	29	25	17

2	56	40	8
3	82	45	-27
4	110	40	-88
5	130	25	-180
6	151	0	-290
7	170	-35	-430
8	190	-80	-590
9	210	-140	-780
10	220	-220	-1000
11	230	-280	-1200

Table 2 (cont.). Data for the comparative study of the change in position on moon, earth, and Jupiter

Time (s)	Moon Flight (m)	Earth Flight (m)	Jupiter Flight (m)
12	240	-360	-1500
13	250	-460	-1800
14	260	-500	-2100
15	270	-700	-2500
16	280	-800	-2800
17	280	-900	-3200
18	280	-1100	-3700
19	280	-1200	-4100
20	280	-1400	-4600
21	280	-1600	-5100
22	270	-1800	-5600
23	270	-2000	-6200
24	260	-2200	-6800
25	250	-2400	-7400
26	240	-2600	-8000
27	230	-2800	-8700
28	210	-3100	-9400
29	200	-3300	-10000
30	180	-3600	-11000
31	160	-3900	-12000
32	140	-4200	-12000
33	120	-4500	-13000
34	95	-4800	-14000
35	70	-5100	-15000
36	43	-5400	-16000
37	14	-5700	-17000
38	-15	-6100	-18000
39	-46	-6400	-19000
40	-80	-6800	-20000

Table 3 provides information concerning changes in velocity that would occur on all three bodies during the time it takes for the full flight on the moon. A good question for checking for understanding would be to have students use this table to determine the initial velocity they would have to give to a ball on the earth or Jupiter to keep it in the air for the duration of the moon flight. [Answer: 370 m/s (830 mi/hr) on the earth and 960 m/s (2200 mi/hr) on Jupiter].

Table 3. Data for the comparative study of the change in velocity on moon, earth, and Jupiter

Time (s)	Moon Flight (m/s)	Earth Flight (m/s)	Jupiter Flight (m/s)
0	30	30	30
1	28	20	4
2	27	10	-22
3	25	0	-48
4	24	-10	-74
5	22	-20	-100
6	20	-30	-130
7	19	-40	-150
8	17	-50	-180
9	16	-60	-200
10	14	-70	-230
11	12	-80	-260
12	11	-90	-280
13	9.2	-100	-310
14	8.6	-110	-330
15	6.0	-120	-360
16	4.4	-130	-390
17	2.8	-140	-410
18	1.2	-150	-440
19	-0.40	-160	-460
20	-2.0	-170	-490
21	-3.6	-180	-520
22	-5.2	-190	-540
23	-6.8	-200	-570
24	-8.4	-210	-600
25	-10	-220	-620
26	-11	-230	-650
27	-13	-240	-670
28	-14	-250	-700
29	-16	-260	-720
30	-18	-270	-750
31	-19	-280	-780
32	-21	-290	-800
33	-22	-300	-830
34	-24	-310	-850
35	-26	-320	-880
36	-27	-330	-910
37	-29	-340	-930
38	-30	-350	-960
39	-32	-360	-990
40	-34	-370	-1000