Gravity and Orbits

PhET Sim Design Document

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Public URL:

http://docs.google.com/View?id=dc7mbgpd_397hc5tmkgs

Contents

Audience

Middle school students (5-8th grade)

Learning Goals

- Understand that gravity is the force that governs the motion of our solar system.
- Draw motion and forces on orbiting planets and moons
- Qualitatively predict how motion would change if gravity was stronger or weaker, and planets/sun more or less massive

Related Jeffco Content Standards

Grades 6 through 8

Students should add more detail to their picture of the universe, pay increasing attention to matters of scale, and back up their understanding with activities using a variety of astronomical tools. Student access to star finders, telescopes, computer simulations of planetary orbits, or a planetarium can be useful at this level. Figuring out and constructing models of size and distance—for example, of the planets within the solar system—is probably the most effective activity. Models with three dimensions are preferable to pictures and diagrams. Everyone should experience trying to fashion a physical model of the solar system in which the same scale is used for the sizes of the objects and the distances between them (as distinct from most illustrations, in which distances are underrepresented by a factor of 10 or more).

By the end of the 8th grade, students should know that:

* The sun is a medium-sized star located near the edge of a disc-shaped galaxy of stars, part of which can be seen as a glowing band of light that spans the sky on a very clear night. 4A/M1a

* The universe contains many billions of galaxies, and each galaxy contains many billions of stars. To the naked eye, even the closest of these galaxies is no more than a dim, fuzzy spot. 4A/M1bc

* The sun is many thousands of times closer to the earth than any other star. Light from the sun takes a few minutes to reach the earth, but light from the next nearest star takes a few years to arrive. The trip to that star would take the fastest rocket thousands

of years. 4A/M2abc

* Some distant galaxies are so far away that their light takes several billion years to reach the earth. People on earth, therefore, see them as they were that long ago in the past. 4A/M2de

* Nine planets of very different size, composition, and surface features move around the sun in nearly circular orbits. Some planets have a variety of moons and even flat rings of rock and ice particles orbiting around them. Some of these planets and moons show evidence of geologic activity. The earth is orbited by one moon, many artificial satellites, and debris. 4A/M3

* Many chunks of rock orbit the sun. Those that meet the earth glow and disintegrate from friction as they plunge through the atmosphere—and sometimes impact the ground. Other chunks of rock mixed with ice have long, off-center orbits that carry them close to the sun, where the sun's radiation (of light and particles) boils off frozen materials from their surfaces and pushes it into a long, illuminated tail. 4A/M4*

Interviews:

UG1M (March 7th)

Background: Sociology degree, now pre-Physical Therapy student

Currently taking Physics 1 and General Chemistry II

Has interviewed once before (Molecules and Light)

Uses PhET website and has used Moving Man in class

Intro Tab: Finds all systems (Sun/Earth, Earth/Satellite etc.)

Doesn't understand mass units at first, figures it out

Finds radio buttons for path, velocity, etc.

Finds Zoom

-E/S mode

Increases mass of Earth, looking at toolbar doesn't notice satellite blows up

Confused by what bar for satellite does, since mass increase is small in comparison, figure it out

Uses reset and reset all with no problems

- S/E/M mode

Likes showing path

uses 'centripetal force' to describe the gravity vectors most of the time

Turns gravity off, then back on quickly, thinks he knows what it will do

Notices that the orbit has changed from turning gravity off

*Sun drifts in S/E/M mode, should not do this

He can't find the moon

Rarely uses the 'Return Object' button, prefers 'Reset'

*'Return Object' button flickers on and off in a nonintuitive way. Student doesn't seem bothered by it.

- E/M mode

Finds 'To Scale' tab

Thinks it's cool to start, though later thinks it's hard to see

Thinks vectors may be confusing to some, particularly when they overlap

Finds measuring tape, doesn't move it

Had to prompt that you could move the objects directly and using the velocity vectors.

Student Suggestions:

- A distance measure for the "Intro" tab, to help with comparisons of orbits for example
- Would like to be able to move the screen and zoom in, like in "google maps"
- Would like to be able to zoom out more in 'To Scale' tab, perhaps even see other planets

Other Thoughts:

This student seemed to think that all orbits, regardless of how they came to exist, would end up back at the 'true' orbit (the current real orbit). Wanted a quantitative measure to see how the orbits changed over time as they moved back to the 'true' orbit.

UG2F (March 7th)

Background: Psychology degree, pre-Med

Taking Physics II, Gen Chem II, Bio II, Genetics

Sim Use: John Travoltage and Circuits in Physics course

Intro Tab:

Finds various systems, only selects top two, though

Finds grid, vectors and mass

Finds “Reset all”, not sure if it did what she expected

- E/M mode

After changing the mass of things, Earth starts to float around (check if correct)

Finds slow/fast slider

Couldn’t restart days simultaneously with orbit by hand, tries for awhile then asks me. I point out that maybe ‘restart’ will do it.

- S/E/M

Notices that motion of sun different in this mode than in the S/E mode

Spends a lot of time comparing S/E/M mode and S/E mode.

Concludes that sun motion in S/E/M mode is just incorrect.

Uses “Reset” to describe “Restart” button (this may be better phrasing)

Likes path view of moon’s orbit in S/E/M and velocity vectors, but uses path most

“never thought of the motion looking quite like that”

Spends a lot of time comparing E/S system to S/E/M, looking at motion of moon

Questions Satellites time around the Earth, asks if that's correct

Checks time of Earth's orbit around the sun

Concludes these are accurate

*Check path after hitting 'return object' in S/E/M mode

Likes S/E/M mode best

She asks for a measure of distance, I point out that there is a second tab with measuring tape

"To Scale" Tab

Uses measuring tape, doesn't move it

*easy to decouple to moon from the earth in S/E/M by changing sizes...double check

Accidentally uses 'Restart' to 'Play'

UG3F (March 15th)

Major: Humanities/Pre-med

Science Classes: General Chemistry 1, Physics 1, currently in General Chemistry II, Physics II

Used PhET sim once or twice in Physics 1

Moves Sun/Earth

Finds forces, velocity, mass

Crashes earth into sun

Uses play/pause button

Moves ISS

Finds grid

**S/E/M mode masses wrong

?does the velocity of the moon change, or is it pseudo 3D

changes mass of sun, losses earth.

Resets day counter

Uses restart/reset

Turns gravity off, watches sun disappear

Turns gravity on, expects earth to come back but doesn't

Uses zoom out

Thinks that if the earth got out of orbit (farther from the sun) we would just freeze "that's weird to think about..."

*Wonders why in Eart/ISS the ISS always goes 'up' to start, even with gravity off. She found this confusing.

Uses grid to check if orbit is staying constant

Uses 'back' button

Recognizes that if the orbit of the earth were farther away, then the years would be longer.

"if the sun were half as close as it is now, we would definitely burn up"

Notices that moon takes about a month to go around the earth. Thought that the moon should go around

the earth once every day.

Wonders if the population got large enough, would that effect the gravitational pull.

“What happens if the sun moves at a greater velocity than the earth?” sets up scenario where she increases the velocity of the sun. Sun moves away from earth/moon.

“I didn’t realize the sun was that much bigger than the Earth” while comparing masses.

Notices that if the moon is moved from the earth, the earth still follows the same orbit.

Asks how ‘they can get the ISS to orbit so fast”

“Wonder if they’ve tried changing it’s [ISS] velocity?”

“They should experiment with that!” (changing the velocity of the ISS and see how the orbit changes.

* Would like distance measure in cartoon mode

“Is the earth perfectly in orbit, or does it change?”

*Would like to be able to make the moon equal in mass to the earth

“Do you know, like, is there a specific gravity of the sun, or is it based of the earth’s gravity?” Cause you know how the gravity on the Earth was, you know, what was discovered, but do you know if there’s one from the Sun, like from itself, without the effect of the Earth?”

Uses the arrows to figure out that the gravity seems equal between the earth and the sun as you bring them closer.

Teacher Tips Notes

- Explanation of which gravity vectors are shown (Moon/Earth not shown in Sun/Earth/Moon mode)
- Objects can be moved (middle school students find this immediately, adults tend to not find this)
- Orbit of ISS not accurate
- Grid can be used as a distance measure in cartoon mode
- Include description of how the sliders work (as of version 1.00.12 slider ticks go .5, 1, 1.5, 2x)

General Issues from Interviews:

- **More intuitive appearance of the "Return Object" button, it seems to flicker on and off unexpectedly for what's on screen**

NP: Perhaps the object needs to go 15% beyond edge before button comes on.

Implemented in 1.00.9

- **Perhaps change "Restart" To "Reset"**

Implemented in version 1.00.10

- **Start appearance of measuring tape in a less intuitive place, to see if that prompts students to move it**

NP: Agrees this should be moved.

Implemented in version 1.00.10

- Ask Sam about having a 'permanent path' option

EM: Thought about this...it may be more problematic as students may play with making art again.

- In "Intro Tab", sun should remain fixed in place, regardless of what size earth/moon

are. (competition here between what's intuitive for sun/earth system and what might be expected from the presented sizes)

Discussion

User issue:

Q:"Can you have the Earth rotate under the ISS so that it looks more realistic? It's also not orbiting in the correct inclination of 51.6 degrees. The ISS does not go over the poles."

EM: If I understand this correctly, the user wants the satellite to not orbit over the poles. In order to do this, i think the image of the earth would need to be changed, probably for only the modes in which the satellite is shown.

SR: According to this website, the ISS orbits in a circular orbit around the earth on a plane 51.6 degrees to the equator.

http://www.challenger.org/programs/iss/iss.cfm

It looks like we would also have to handle earth rotation to get this right.

Maybe the best solution to keep the sim simple would be to show a fictional satellite instead of the real space station. What do you think?

EM: Where did the current earth picture come from?
SR: I think it is from NASA

EM: Would it make sense to change the earth in only the modes with the satellite showing, or would it need to be changed universally throughout the sim?
SR: It's slightly simpler to keep it consistent throughout the sim but not a problem if we want it to be different in some modes.

NP: I don't think we want to make the earth rotate, both because it will be expensive and an additional representation for students to be mesmerized by. We want them to watch the satellite motion, not the earth.

I also think it's probably better to show a familiar image of the earth, even if it means not having the right trajectory for the satellite. Students may not recognize an earth that has been rotated 51deg.

EM: I agree that the for the purposes of the sim, I don't think the earth rotating would be useful. I don't see much of an issues showing the earth slightly tilted, using a static image. My guess is that students likely recognize the earth based on the blue/white coloring (ocean/clouds) and less on the actual fine grain representations of the continents, but I could be wrong about this.

I don't have a strong feeling about this, I just figured if changing only the Earth in the Earth/satellite representation to a different static image of the Earth (rotated by whatever degrees) was easy to do, it probably wouldn't hurt anything and might be useful for some teachers talking about the ISS.

NP: I agree - in another email I looked back at he sim and realized that it's hard to know what the tilt is without looking really closely (because of the clouds and such). So replacing the image with one that is more correct is fine.

SR: I'm still confused about how/whether we should address this problem. The orbit of the space station around the earth is not over a fixed trajectory; so why would changing images of the earth solve this problem? Can you be more specific about what your recommended solution is and how it would solve the problem? Is this just about getting the 51.6 degree with respect to the equator correct? Have you seen an image that

would be suitable to put in the sim? (3rd image in link EM referred to is unsuitable because it still would show the space station orbiting past the poles, and because it shows fixed sunlight.)

Why not just change the terminology in the sim so that nobody mistakes our fictional satellite for the real space station, since the details of the actual space station orbital and earth rotation are outside the scope of this 2d sim about gravity?

EM: Since the goal of the sim has nothing in particular to do with the specific orbit of the ISS, perhaps we should just leave it alone, and I'll make a note in the teacher tips that the orbit of the satellite is only to demonstrate a general orbit.

Q: Can you make the sun stay in place in the cartoon Sun/Earth/Moon mode?
SR: Increasing the Earth + Moon mass was an idea JO suggested to make the orbits more stable--after reducing their mass so that the sun doesn't move very much, it's been difficult to find a set of initial conditions that yields an system that lasts much more more than an orbit. The main problem is that if the sun is relatively too massive (and hence stationary), then it will capture the moon, since the moon has to be so far away from the earth in cartoon mode.

How important is it that the sun remain stationary? How much more time should I spend looking for stable orbits with a smaller relative sun mass? Is there a systematic way to identify a set of initial conditions that will result in a stable orbit (perhaps there isn't due to sensitive dependence on initial conditions)? I have already written a program that helps me to explore the parameter space by iterating through parameters near a local optimum, but even with this I'm having trouble getting a stable orbit for very long.

I also considered centering the camera on the sun, but then thought that putting the system in a noninertial reference frame could lead to other confusing behavior (especially regarding treatment of velocity vectors).

EM: It's confusing to students for the Sun to remain stationary (or at least appear to remain stationary) in other modes, but to move in Sun/Earth/Moon mode. To me, the issue is more consistency. I don't know if it will confuse students if in all cases the Sun moved, but we could find that out in interviews. I don't think it's necessary to have the camera centered on the Sun...that may prove more confusing to students.

Status Meeting 03/17/11 (from meeting minutes)
SR: Another problem is that Emily asked to have the sun stable in the 'Sun Earth Moon' view. Having the sun moving keeps orbit. Otherwise moon crashes into earth.
KP: Maybe ask Mike Dubson about this
TL: I remember that I thought when you changed the physics I thought it was weird the sun was moving
MD: It is accurate that the sun moves. It is a nice learning goal.
KP: for Middle School??
MD: alright… here's another way of doing this… do a coordinate transfer. If you want physically correct behavior, then you need to leave the physics.
SR: will look with you at trying to find a solution
KP: writing an email for a meeting for GAO

SR: At the 3/17/2011 PhET meeting, we decided I should try to work with Mike Dubson to find a stable orbit for cartoon sun/earth/moon with a stationery sun--there is no guarantee that such an orbit actually exists, but we plan to spend more time looking unless/until I hear otherwise. From your response in the design doc, is your recommendation that we instead try to make the sun move in the Sun/Earth mode?

Q: When to republish?

SR: What else needs to be done before we can publish this as 1.01? Are you going to re-interview before we publish 1.01?

To discuss in 3/21/11 meeting

Outstanding issues

- Decide if ISS image, wording or earth image should be changed.
- In E/M mode in both Cartoon and To Scale tab, start moon to the right

SR: this is because in the S/E/M mode the moon starts at the top, keeping it the same is consistent.

- In S/E/M mode, stop the sun from moving so much

- (Seemingly random bug) In S/E/M mode, when return object is hit, sun spirals off screen, and moon explodes into the place where the sun was. (Sam explained, moon crashing into the earth, and existing velocity from the return object)
- Masses incorrect in S/E/M mode

What needs to be completed before republishing?

- Rename "Intro" to "Cartoon"
- No masses shown in the first tab
- Ask Texas teachers what they think about 'star' versus 'sun'
- Rescale the time, so that earth goes around the sun in the a year

NP: thinks system should pause after hitting return object

Ask teachers how they feel about:

- Sun moving
- Separation of cartoon and to scale
- not able to draw with it
- naming 'star' versus 'sun'

Design doc prior to 03/11
Sun and Planet

A modified version of My Solar System aimed at Middle school:

- Remove sweeping
- Change to something more intuitive than "earth masses", maybe just "mass, small to large"
    - very small to small for planet
    - large to very large for sun
    - show values option, shown in "earth masses"
    - write "thousand", "million" earth masses, not exponential notation
- keep forces
- make it "sun" and "planet" (not earth)
- change masses with sliders
- change positions by dragging

- remove traces (off by default)
- start with earth / sun system (so sun doesn't move, earth should be blue)
- can we change velocity?
- have option for planet / moon, but not 2 planets

Implemented a 2nd new version, based on feedback from Peter below.

Modified to meet MS learning goals:

- Understand that gravity is the force that governs the motion of our solar system.
- Draw motion and forces on orbiting planets and moons
- Qualitatively predict how motion would change if gravity was stronger or weaker, and planets/sun more or less massive

Below are from a lesson Trish is writing for 5th grade ODF activity(I believe I have scaffolded these for 5th grade

Learning Goals: (numbered ones are from TEKS) ***(italics are things for teachers)***

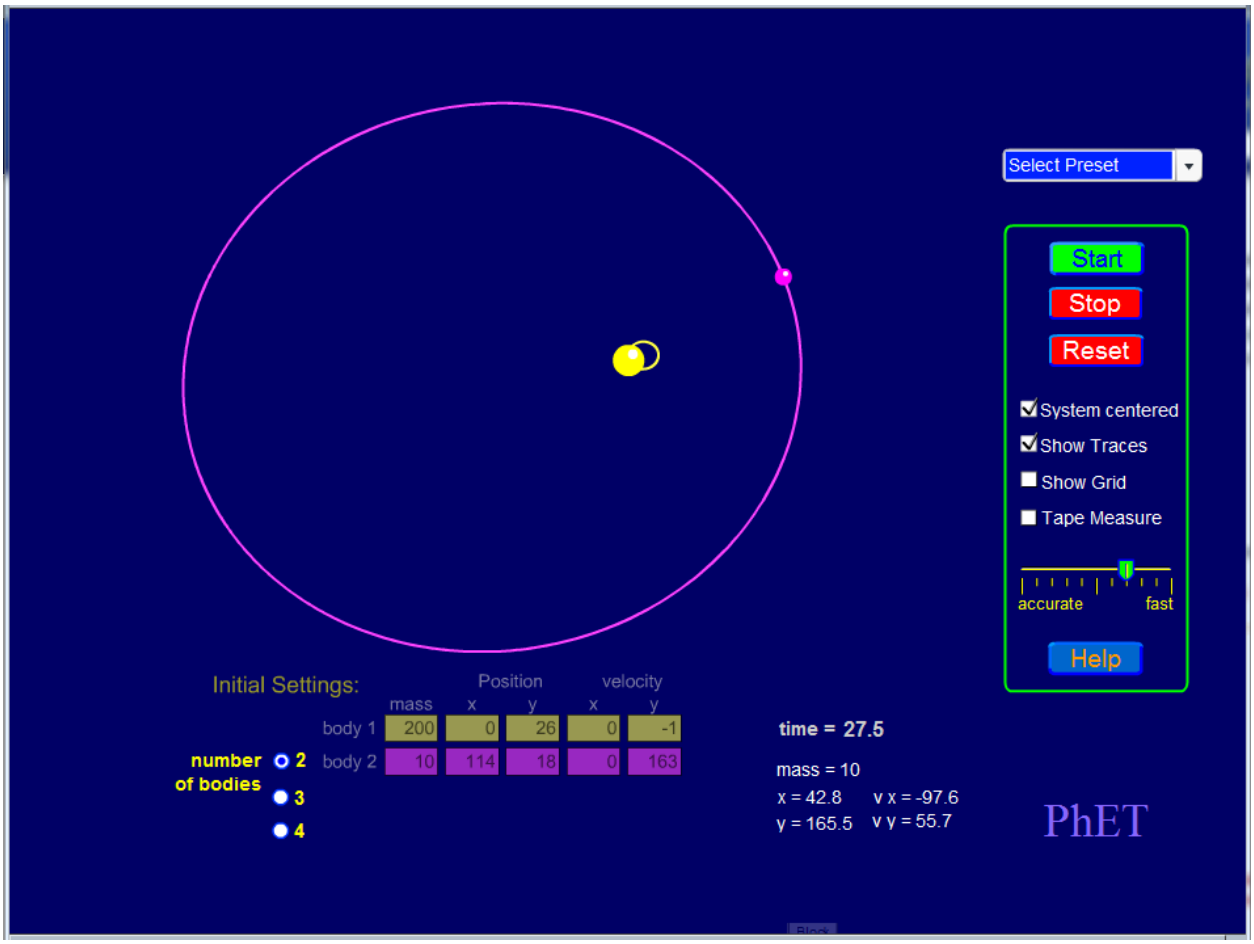
Students will be able to:

- Draw motion of planets, moons and satellites.
    - 3.8(C) construct models that demonstrate the relationship of the Sun, Earth, and Moon, including orbits and positions
    - 4.3 (C) represent the natural world using models including accuracy and size
- Draw diagrams that show how you could explain that gravity is the force that controls the motion of our solar system. *(draw force diagrams)*
- Identify the variables that affect the strength of the gravity
    - 5.8 (D) identify and compare the physical characteristics of the Sun, Earth, and Moon.

- Predict how motion would change if gravity was stronger or weaker.
    - 4.6D design an experiment to test the effect of force gravity on an object.
    - Include how the gravity might be stronger or weaker

-pat loeblein 1/4/11 10:58 AM

Original My Solar System for comparison:



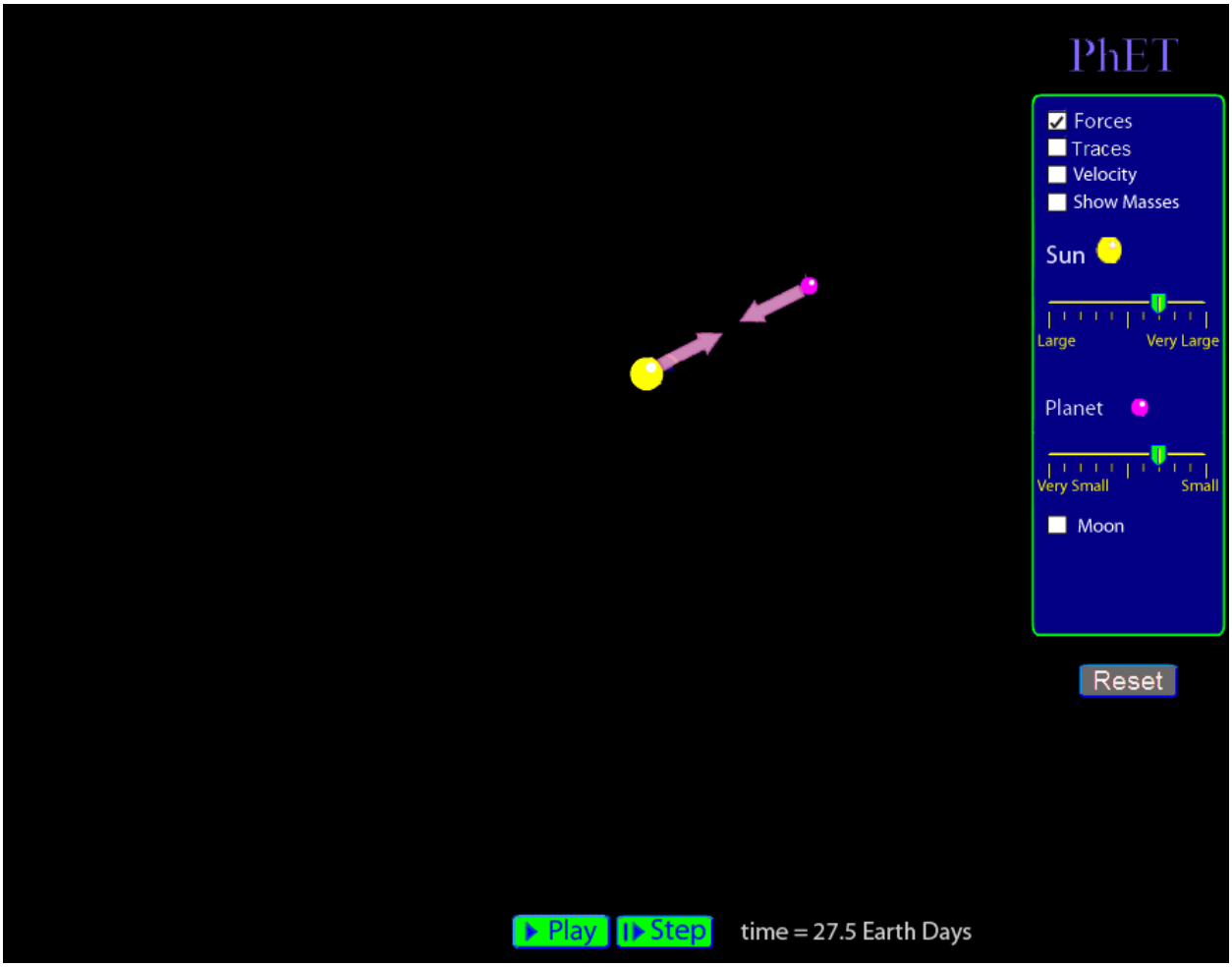
Pared-down version

- Only have the sun and single planet. Can choose to show the Moon using check box at bottom.
    - Does this activate a mass slider for Moon? Or fixed mass?

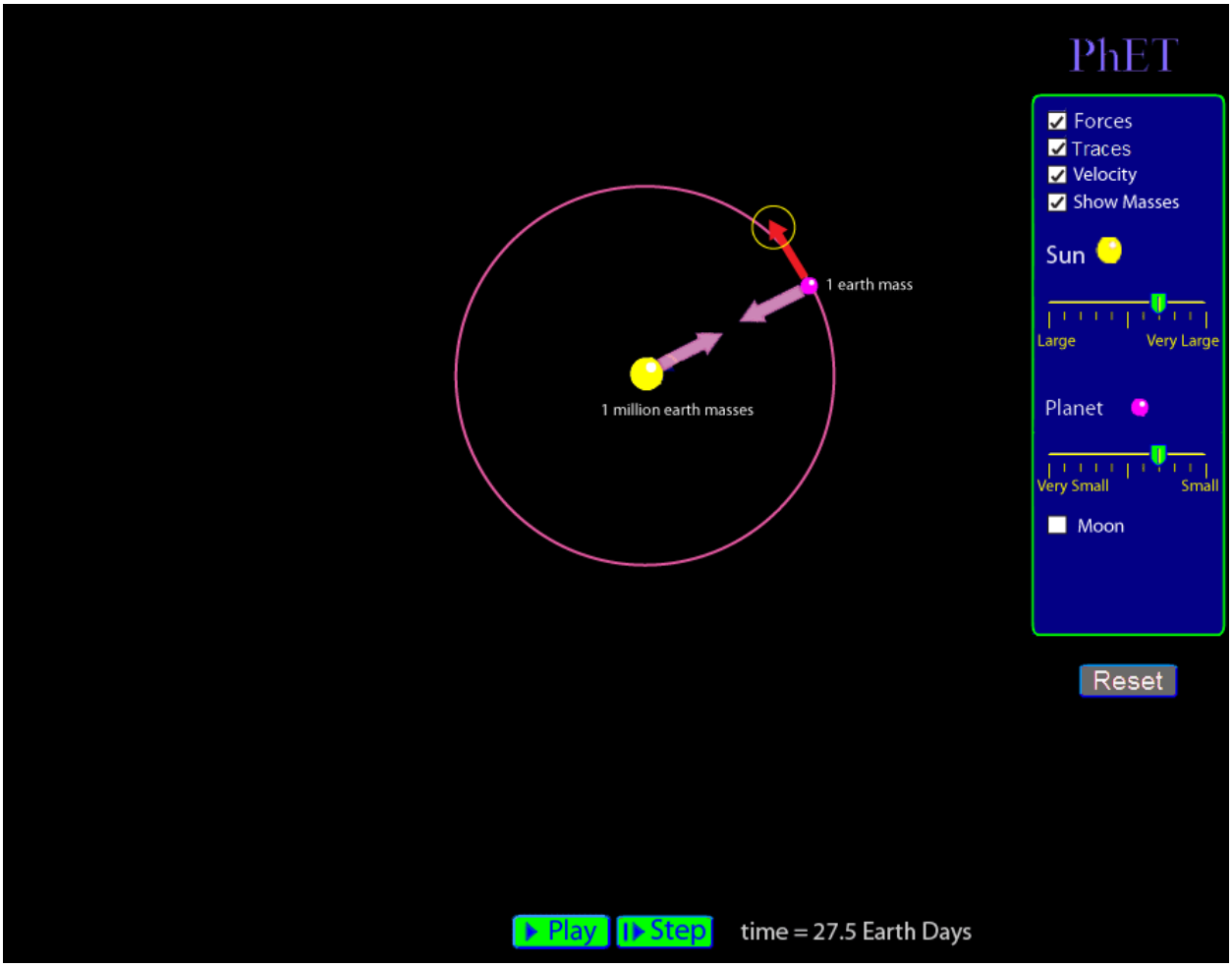
- M_sun goes from "large" to "very large", let's say 0.1 to 10 million earth masses
- M_planet goes from "very small" to "very large", let's say 0.1 to 10 earth masses
    - Note that planet diameter needs to scale as mass^(1/3), since mass ~ volume ~ diameter^3
- Preset positions and velocities for planet so that it goes in a circle.
- "Forces" show gravitational force, checked by default
    - F = G M_sun * M_planet / r^2
    - Will need to use model (from Mike D) for including moon and calculating orbits
    - Add force arrows to objects - this will be the total force on each object (should be easy, I think acceleration is already calculated, so F=ma)
- Can grab bodies and move them around
- Can set velocity if "velocity" is checked
- Can "Show Masses", which shows the mass of bodies in "earth masses"
    - Might change this to "Show Values", but we are only showing mass values, so could be confusing
- Background color in play area to black
- Move control panel to right-hand edge (leave it same dark blue background color)
- Remove items from play area:
    - Move "Number of Bodies" from play area to control panel, relabel to "Number of Planets"
    - Move time readout to under reset button in control panel
    - Remove the word "show" from all check box labels
    - Remove everything else from the play area
    - Remove "Select Preset" menu
    - Remove "accurate-fast" slider
    - Remove Help (?)
- Play control changes:
    - Add "Step" button to step through time
    - Remove "Stop" and use single button for "Play/Pause"

    - Add playback control icons to buttons (start, step)
    - Change "Reset" button color to gray, move to under control panel
- Add sliders to adjust mass of planets
    - Add icons for each planet next to slider label
- Time is in "earth days"

Start State



All Options On


PhET
Forces
Traces
Velocity
Show Masses
Sun
Large
Very Large
Planet
Very Small
Small
Moon
Reset
1 earth mass
1 million earth masses
Play
Step
time = 27.5 Earth Days