Classroom Demonstration Guidelines
(Retention of an Atmosphere Module)

The following sequence of directions are steps an instructor might choose to follow in demonstrating the simulations in the Atmospheric Retention Module in a classroom setting. We provide these suggestions with appropriate questions (shown in bold italics) to pose to the class as an aid in promoting interactivity. We encourage instructors to adapt these suggestions to their particular educational goals and the needs of their class.

Animation Demonstration Directions	Interactive Questions
Load the page entitled Projectile simulation and scroll down to the **Projectile Motion Simulator**. Start the simulation and explain to students how it allows you to launch a particle vertically and specify velocity. You can also specify the gravity through the mass and radius of the planetary body.	
Click **fire** to launch a particle with the default parameters. You may need to click **start over** and **fire** the particle again.	Note that our simulator is configured for the Earth and we are firing our particle at 1 km/s. ***What causes the particle to slow down, stop, and eventually fall back to Earth?*** (gravity) ***How high did the particle go?*** (51.4 km)
This is a good time to talk about the fact that this simulator only show the effects of gravity – there is no rotation or air resistance. A rifle bullet would get slowed down considerably by an atmosphere.	The muzzle velocity of a rifle bullet is about 1 km/s. ***Do you think that rifle bullets really go that high?*** (No)
Change the **initial projectile speed** to 2.0 km/s and **fire** the bullet again.	***What will happen if we increase the launch velocity?*** (It will go higher.) ***How much higher did the particle go than in the initial firing?*** (4 times higher.)
Fire the projectile several more times with **initial projectile speeds** of 4.0, 6.0, 8.0, and finally 10.0 km/s.	***If we keep increasing the launch velocity, will the particle eventually escape from the Earth?*** (Yes) Note how the simulation is taking longer and longer, the 10.0 km/s launch takes 5.34 hours.
Fire the projectile once again with an **initial projectile speed** of 12.0 km/s and let the simulation run a couple of days.	***Is the velocity still decreasing?*** (No) ***Will this particle ever return to Earth?*** (No)
Define the escape velocity – the vertical velocity a particle needs to (just) escape the gravity of the Earth. Thus, the particle will come to a stop only after an infinite amount of time at a very large distance. Thus, escape	

velocities cannot be determined accurately with this simulator. Return the **initial projectile speed** 1.0 km/s and increase the planet mass to 2.0 M_{earth}.	***What is the escape velocity of the Earth?*** (11.4 km/s) Remind students that the particle rose to 51.4 km on the Earth. ***Will increasing the mass of the planet affect the escape velocity and the height to which the particle rises?*** (Yes, it will increase gravity and the escape velocity so the particle will not rise as high?) Note that the particle rises to 25.6 km, half as high.
Increase the **planet radius** to 2.0 R_{earth}. Point out that the height that the particles rises is not the best indicator of escape velocity. Since it is equal to $\sqrt{\frac{2GM}{R}}$, escape velocity is the same when M and R are both 1 or both 2. While the acceleration due to gravity is $g = \frac{GM}{R^2}$, so the particle will rise much higher when M and R are 2.	***Will increasing the radius of the planet now decrease the escape velocity*** (Yes, it will decrease the escape velocity?)
Open the **Gas Retention Simulator**. Discuss with students that this simulator allows one to place different gases in a chamber, control the temperatures, and look at the distribution of speeds for the particles of each gas. Use the **select gas to add** menu in the **Gases** panel to add **ammonia** to the Chamber. Click **start simulation**. Click **show draggable cursor**, drag the cursor to the peak of the speed distribution, and read off the peak (most probable) velocity.	***Are all of the ammonia particles moving at the same speed?*** (No) ***What is the most common speed – at what speed are the most particles moving?*** (The peak of the distribution – about 540 m/s.) ***Is the peak of the distribution the average particle velocity?*** (No.) ***Why not – is the curve symmetric about the peak velocity?*** (No, there is a high speed tail to the right.) ***Can you estimate the location of the average velocity?*** (A little to the right of the peak velocity.)
Click **stop simulation** to change the temperature. Drag the temperature slider to 100 K to illustrate this – and then return the temperature to 300K. You may wish to run the simulation at various tempatures. Click stop simulation. Use the **select gas to**	***What will happen if the temperature is lowered to 100 K?*** (The entire distribution will shift to the left and become more narrow.)

add menu in the **Gases** panel to add **hydrogen** to the Chamber.	***Will the hydrogen particle on average move faster or slower than the ammonia particles?*** (faster) ***Why?*** (Because the hydrogen particles have much lower mass). ***Is the shape of the hydrogen speed distribution the same as that of the ammonia speed distribution?*** (No, the hydrogen distribution is much broader – there is a larger range of speeds.)
Click **start simulation**. Encourage students to look for this difference in velocity.	***Can you identify an ammonia particle that you can follow around in the chamber?*** (Yes.) ***Can you identify a hydrogen particle that you can follow around in the chamber?*** (Yes, but it is much harder to find a slow moving particle.)
Click **stop simulation**. Talk about how the walls of the chamber can function analogously to a planet's escape velocity. Click ***allow escape from chamber*** and point out the escape velocity of 1500 m/s on the ***Distribution Plot***.	You may wish to pause and have students discuss this in groups. ***What do you think will happen if we run the simulation?*** (The hydrogen will quickly escape while the ammonia will be relatively unaffected.)
Click **start simulation**.	
Click **stop simulation** and **reset proportions**. Change the **escape speed** to its maximum value of 1900 m/s and lower **temperature** to its minimum value of 100 K. Click **start simulation**. Hydrogen will escape much more slowly, but will still escape.	***How can the simulation conditions be changed so that hydrogen is retained for a longer period of time?*** (Raise the escape speed and lower the temperature.)
Open the **Gas Retention Plot**. Discuss with the student that this animated plot allows one to graph planetary bodies in terms of their escape velocity and temperature and gases in terms of their average velocities at various temperatures. Drag red circle to the Earth's approximate location. Check **show terrestrial planets**. You can then drag the red circle to the Earth location and it will snap to it.	***Where would the Earth be on this plot?*** (At an escape velocity of 11.2 km/s and a temperature of about 280 K.) ***Where would Saturn be on this plot compared to the Earth?*** (To the upper left – a higher escape velocity and a lower temperature.)
Check **show gas giants**. Check **show icy bodies and moons**.	***Where would Pluto be on this plot?*** (In the lower left – at a lower temperature than Neptune and a very low escape velocity.)

In the **Gases** panel, check the **show in plot** box for **helium**. You should discuss with students the significance of the dotted line (10 times v_{avg}, bodies with escapes speeds above this can retain the gas over long time scales) and that the coloring fades to white at 6 times v_{avg} indicating that at escape speeds below this the gas will quickly escape.	***What bodies in the solar system could retain helium?*** (Any of the gas giants.)
Uncheck helium and check **nitrogen**.	***What bodies in the solar system could retain nitrogen?*** (Any of the gas giants and Earth, Venus, and Mars.)