Gravity Notes
(Possible outline for the classroom discussion of gravity)

There are a number of good references on the web that can provide additional background. This list is indicative of what one might find from a quick search:

http://en.wikipedia.org/wiki/Gravity#Gravity_and_astronomy
http://www-scf.usc.edu/~kallos/gravity.htm
http://csep10.phys.utk.edu/astr161/lect/history/newtongrav.html
http://www.stanford.edu/~buzzt/gravity.html
http://www.newton.ac.uk/newtlife.html

The Adler Planetarium document above (third URL) gives a particularly concise account of the material below:

Part I. Newton’s Universal Law of Gravitation
- Every two objects attract each other because of their mass. Newton’s law describes the interaction between two objects with mass.
  - How does that attraction behave as you double the mass of the two objects? *(The force doubles as each mass doubles.)*
    - If both masses double, the force would increase by a factor of four.
    - If you triple the mass of one, the force triples.
  - If you double the distance between two masses, how does the force change? *(The force would get smaller by a factor of four.)*
    - Tripling the distance makes the force 1/9 of the original force.
  - What other variable influences the gravitational force? (*None – not color, time of day, etc.*)
- According to legend, Newton went to the family farm in the country in 1665 to escape the Black Plague and noticed an apple falling. This led him to thinking about how high gravity reached. Top of a barn, a mountain? To the Moon? To the stars?
  - Newton was aware of Kepler’s three laws of planetary motion.
    1. Planets move in ellipses about the Sun with the Sun at one of the foci - almost circular.
    2. Equal areas are swept out by a line from the planet to the Sun in equal time periods.
    3. The period squared for a planet is proportional to the radius of circle cubed.
      - Gravity might be responsible for this type of motion, if it reached out far enough.
- He imagined if you shot a cannon off the top of a mountain at just the right speed, it would orbit the Earth.
  - Displaying the Handout: *Gravity, Projectile Motion, and Orbital Motion*, assist with this thought. (It has diagrams and logic.)
  - He applied this logic to the Moon falling around the Earth, knowing ratios of distances and times for an orbit.
- The numbers fit his gravity theory and accounted for the orbital motion of the Moon around the Earth.
  - The theory fit! However, Newton did not publish these for 20 years at the urging of friends.
  \[ F_g = G \left( \frac{m_1 m_2}{d^2} \right) \]
The gravitation equation is given, but the value of G was not known until measured by Cavendish later.

- This equation is universal. Every two masses in the Universe are attracted to each other with a value given by this formula. G is the constant of proportionality, making the proportionalities given above into an equation. The value of G was not measured experimentally until much later by Henry Cavendish.
- As shown below in the graphic for the mass and radius of the Earth, this equation gives the gravitational force at the surface of the Earth.
- For objects orbiting another body, gravity provides the centripetal force necessary to keep the object in orbit.

**Law of Universal Gravitation**

Every object in the Universe attracts every other object with a force directed along the line of centers for the two objects that is proportional to the product of their masses and inversely proportional to the square of the separation between the two objects.

\[ F_g = G \frac{m_1 m_2}{r^2} \]

**Weight**

\[ F_g = G \frac{m_1 m_2}{r^2} = mg \]

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**Part II. Einstein, Gravity, and General Relativity**

The basis of this topic is the equivalence of inertial and gravitational mass. Einstein thought about this in great detail and came up with startling conclusions.

- The question he asked was, “How do we define a straight line?” Historically, this question was answered by the phrase “the path light travels”, and that concept is used in laser-based devices to hang pictures straight, survey land, and construct level buildings.
- Consider the situation of a scientist in a closed space ship in deep outer space where the tug of external forces is negligible. In this situation, a rock floats and light travels straight across the room to a spot of equal height. Now, a change takes place where the rock “falls” to the floor as observed by the scientist.
  - There is no experiment that can tell whether a gravity source (planet for example) has moved under the ship or that the ship is accelerating forward. In one case, we would say that the gravitational property of mass reacts to the gravity. In the other case, we would say that the inertial mass property resists the acceleration.
  - Surprisingly, the light beam would also react and “bend” downward from the original spot. So, how do we (how did Einstein) explain this?
- Einstein’s general theory of relativity approaches the concept of gravity, not as a force so much as a distortion of the space time continuum. Thus, gravity produces a depression in this fabric of space.
• The question of a straight line loses meaning. Light and matter both react to the curvature of space.
• If the depression is deep enough (gravity strong enough by Newton’s equation), light cannot escape from the depression and we have a black hole.
• The space distortion is obvious from the diagram, but the time distortion is also real and has been verified. Time passes more slowly in a strong gravitational field.
• A number of small astronomical discrepancies from Newton’s equations have been explained by Einstein’s theory, including the bending of light (as a lens) around massive objects and the slowing of clocks due to gravity.