Period 13 Activity Solutions: Energy Balance of the Earth

13.1 Sensitivity of Systems to Initial Conditions

1) Motion and Newton's Laws

Your instructor will demonstrate a cart moving on a track.

a) Is it possible to predict the motion of the cart? **_Yes, it moves back and forth along the track_**

b) What set of laws govern the motion of the cart? **__Newton's Laws of motion__**

c) What determines the initial speed of the cart? **_The amount of force given to the cart to start it moving._**

d) Your instructor will demonstrate two identical carts that move at different speeds. What is the difference in their motion?

The two carts started with different initial conditions. One cart was pushed with more force.

2) Predictable and unpredictable systems

Your instructor will demonstrate a simple pendulum, starting its motion several times.

a) Is it possible to predict the motion of this pendulum each time? **Yes, it swings back and forth in a regular pattern.**

b) What set of laws govern the motion of the pendulum? **Newton's laws of gravitational force and motion**

c) Your instructor will demonstrate a modified pendulum that includes a spring. Does this pendulum also follow Newton's Laws? **Yes** Can you predict the motion of this pendulum? **No, it moves unpredictably.**

d) When the second pendulum is repeatedly set in motion with as close to identical conditions as possible, does this pendulum behave the same each time? **No** How does the spring change the character of the pendulum?

The spring makes the second pendulum sensitive to variations in the initial conditions.

3) Deterministic systems

As we have seen, both predictable and unpredictable systems follow Newton's Laws.

a) What is the term for a system for which we know the laws governing the system's behavior?

A deterministic system

b) What is the relationship between successive events in a deterministic system?

In a deterministic system, each successive event may be determined from previous events.

c) Are there any systems in nature that are not deterministic?

No, the behavior of all systems can be determined by previous events.

4) Sensitive and non-sensitive systems and initial conditions

Next, we examine the difference between predictable and unpredictable systems.

a) Place the ice cream cone upside down. Tilt the cone slightly to the right side and release it. What happens? **The cone returns to its initial position.**

b) Is the behavior of the cone predictable?

Yes, if the cone is tilted only slightly, it always returns to its initial position.

c) Change the initial conditions by tilting the cone to the left or toward you or away from you and then release the cone. Is the final position of the cone the same in each case?

Yes, the cone returns to its initial position no matter in which direction it is slightly tilted.

d) Is the final position of the cone sensitive to your choice of initial conditions?

No. When the cone is upside down, it is not very sensitive to initial conditions, such as the direction it is tilted.

e) Now turn the cone over and try to balance it on its tip. When you release the cone, can you predict in which direction it will fall? **No** Does the cone on its tip represent a system that is sensitive or not sensitive to the initial conditions?

The cone on its tip represents a sensitive system because it is impossible to predict the direction in which it will fall.

f) What is the difference in the initial conditions that predict which direction the cone will fall?

If the cone leans in one particular direction, it will fall in that direction.

g) What is the difference between a system that is predictable and one that is not predictable?

A predictable system is one that is not greatly affected by (is not sensitive to) the choice of the system's initial conditions. An unpredictable system's behavior is sensitive to its initial conditions.

h) Group Discussion Question: In the examples seen thus far (the carts, the pendulums, and the ice cream cone), what laws govern the motion of the objects? **Newton's Laws** What information do you need in addition to these laws to predict the motion of the objects?

You need to know the initial conditions (the initial positions of the objects.)

5) More examples of sensitive and non-sensitive systems

Your instructor will demonstrate two types of balls.

a) Which ball represents a non-sensitive system? **the round ball**

b) Which ball represents a sensitive system? **the football**

c) Which ball represents a deterministic system? **both balls**

d) Your instructor will demonstrate more systems. For each system, indicate the factors determining the initial conditions. Is each system sensitive or not sensitive to the choice of initial conditions?

Example	Initial Conditions	Sensitive or Non-sensitive
Double pendulum	**The height to which the pendulum arms are raised**	**sensitive**
Magnetic spinner	**The initial position of the spinner arms and the force of the push the arms are given**	**sensitive**
Illumitron ball	**The position of the separated electric charge in the ball**	**sensitive**
Balloons	**The position of the inflated balloon**	**sensitive**

e) Group Discussion Question: Give examples of objects in the room for which you can predict the object's behavior.

Any stationary object, for example, a table

13.2 How to Turn Sensitivity into Probability

6) Probability with Dice

a) Rolling dice has unpredictable results. When you roll a single die, what are the possible outcomes?

When you roll a single die, the result is a 1, 2, 3, 4, 5, or 6

b) What is the probability of each outcome per roll?

1/6 There is one chance in 6 of rolling each number.

c) Roll one die 12 times. For each roll, record the result by marking an X in the corresponding column in the grid below.

10						
9						
8						
7						
6						
5						
4						
3						
2						
1						
	1	**2**	**3**	**4**	**5**	**6**

d) What histogram would you expect based on the probability from part 6.b)?

Two X's in each column

e) What determines the outcome of each roll?

The initial conditions (how you hold and throw the die)

f) Is the system of rolling dice a sensitive system?

Yes. The outcome is unpredictable and is dependent on the initial conditions.

g) Why doesn't your histogram match the probability expectations?

You haven't thrown the die enough times to average out the effect of the initial conditions.

h) Try adjusting the initial conditions of rolling the die so that you get the same result with each roll. Were you successful? Why or why not?

It is not possible to produce the same results each time because this system is too sensitive to the initial condition of how you hold the die.

13.3 Unpredictability in Our Environment

Dice are a simple system in which each outcome has equal probability. Weather prediction is a much more complex system that combines the probability of possible outcomes (whether or not it will rain tomorrow) with initial conditions (the current temperature, barometric pressure, humidity, and winds) around the world.

Next, we examine two of the factors that determine the weather.

7) The Earth's water cycle

a) Describe the components of the Earth's water cycle.

Soil moisture and water from rivers, lakes, and oceans is evaporated by the sun's energy into water vapor. When water vapor in the atmosphere cools sufficiently, it condenses to form clouds. Precipitation from clouds bring the water back to the ground.

b) What drives the water cycle? **Energy from the sun**

c) What are clouds made of?

Clouds consist of tiny water droplets or ice crystals (especially in higher cirrus clouds). Clouds are not made of water vapor, which is invisible.

d) Why do clouds form?

As air rises, it cools. This causes the water vapor in the air to condense into droplets.

e) Why does moisture form on the outside of a cold can of soda? Where does the moisture come from?

Water vapor in the air is cooled in the vicinity of the can. The cooled vapor condenses on the outside of the can.

8) The Earth's winds

a) Explain the two main reasons that winds blow.

1) Winds blow due to the spinning of the Earth, which produces the Coriolis effect, and

2) due to the uneven heating of the Earth's surface, which causes convection currents.

b) What causes land and sea breezes? What role do convection currents play?

During the day, the land heats up more quickly than the water. Air above the land is heated more quickly and rises, creating a region of

low pressure above the beach. Air above the water moves inland toward the region of low pressure. This circulation creates convection currents. At night, the land cools off more quickly than the water. Warm air above the water rises, creating a region of low pressure above the water. Air from the land moves seaward toward the region of low pressure. The night time breeze moves in the opposite direction (out to sea) as the day time breeze.

9) Balance of the Planet as a model of the Earth

Group Discussion Question: Balance of the Planet used 150 variables to simulate the Earth's environment. You were able to choose the initial conditions of many of these variables for each five-year period. What is your opinion of Balance of the Planet as a simulation of the Earth's environment? What would you change about the game?