

## Activity 14 Solutions: Sensitive Systems and Computer Modeling

### 14.1 Sensitivity of Systems to Initial Conditions

#### 1) Predictable and unpredictable systems

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

- Is it possible to predict the motion of this pendulum each time? **Yes, it swings back and forth in a regular pattern.**
- What set of laws govern the motion of the pendulum? **Newton's laws of gravitational force and motion**
- 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.**
- 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.**

#### 2) Deterministic systems

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

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

#### **A deterministic system**

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

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

- Are there any systems in nature that are not deterministic?

**No. If we know all of the equations that govern the behavior of any system, the subsequent behavior of that system can be determined by previous events.**

#### 3) Sensitive and non-sensitive systems and initial conditions

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

- 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.**
- 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 even slightly 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?

#### **4) 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 and whether or not it is released from rest.	sensitive
Magnetic spinner	The initial position of the spinner arms and the force of the push the arms are given	sensitive
Illumintron ball	The position of the separated electric charge in the ball	sensitive
Balloons	The way the inflated balloon is held and released.	sensitive

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

## 14.2 How to Turn Sensitivity into Probability

### 5) 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. Make a histogram in the grid below by darkening one square that corresponds to the number on the die for each roll. At the end, you will have 12 blackened squares.

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

Number on die

- 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.**

### 14.3 Computer Simulations

#### 6) Using Computer Simulations

- a) Why are computer simulations used? Describe situations for which simulations are useful.

**They are useful for simulating dangerous, expensive or impossible experiments without actually doing them. (Examples: flight training, building designs, or experiments involving stars).**

**They are also useful for quickly calculating the results of changing the value of variables. (Examples: weather forecasts, stock market projections or "Balance of the Planet")**

- b) What are some limitations and disadvantages of computer simulations?

**Computer simulations can only reflect reality to the extent that it is understood. The simulation may reflect the bias or opinions of those who wrote the computer program. Simulations may oversimplify reality and they cannot predict the future.**

### 14.4 Balance of the Planet

Your instructor will explain this computer simulation.

#### 7) Energy Sources

- a) We will test whether Balance of the Planet is a sensitive computer simulation by comparing the results of different initial conditions. On the Policy screen, set the taxes and subsidies to **encourage** the use of fossil fuels – coal, oil, and natural gas. Do not change other taxation and subsidy categories. Execute your policies and play the game through 2005 by adjusting the taxes for each 5-year period. Record your scores from the Results screen onto the score sheet. Then exit this game.
- b) Start a new game in which you **discourage** the use of fossil fuels through taxes and subsidies. Play the game through 2005 and record your scores. Exit this game.
- c) Compare the results of these two games.
- 1) When you encourage the use of fossil fuels, which point categories improve?

Which point categories worsen?

- 2) When you discourage the use of fossil fuels, which point categories improve?

Which point categories worsen?

- d) Based on the results of these two games, do you think this computer simulation is sensitive to initial conditions? Why or why not?

**The simulation describes a sensitive system because small changes in one variable can produce large effects in other variables.**

- 8) **World Food Supply** Providing adequate nutrition for people and reducing starvation is a difficult problem to solve in this simulation.

- a) Which tax categories would you increase and which would you decrease to reduce starvation?

**Decrease the fertilizer and pesticide taxes to encourage their use and increase crop yields. Increase the beef tax.**

- b) Why would increasing the beef tax reduce starvation?

**Ten pounds of grain must be fed to cattle to produce one pound of beef. More people can be fed if people are encouraged to eat more grain than beef.**

- c) Which items would you fund to reduce starvation?

**family planning subsidy**

- d) Using your strategies to reduce starvation, play a game to the year 2035. Record the results on the score sheet.
- e) Which point categories improved as a result of your strategies? Which categories worsened?

- 9) **Other Environmental and Societal Issues**

- a) Check the Policy screen and the Results screen for other environmental or societal issues you wish to address with taxes or subsidies. When you have adjusted the tax and subsidy rates, play another game and record your results on the score sheet.
- b) What is the final score from your best game? \_\_\_\_\_

- 10) **Balance of the Planet as a model of the Earth**

Balance of the Planet uses 150 variables to simulate the Earth's environment. You are able to choose the initial conditions of many of these variables for each five-year period.

- a) How does a simulation like Balance of the Planet produce the results you see every 5 years?

**The program has a system of equations that connect the 150 variables. Changes to one variable may affect the outcome of many other variables.**

- b) How could a simulation program such as balance of the Planet be used to develop a series of probable outcomes?

**Based on the explanation given in the video on predicting weather, a program is run many times with slightly different initial conditions. If the results form clusters, you can turn those clusters into probabilities. For example, if a simulation gives a particular result 10% of the time, then that result has a 10% probability of occurring.**

- c) Group Discussion Question: In your opinion, is the Earth's environment a sensitive system in which changes to one variable may produce large effects in other variables?