CHAPTER 2 PRINCIPLES OF SCIENCE AND SYSTEMS

Chapter Overview

This chapter explains the scientific method and its applications to the study of environmental science. The importance of systems, particularly open systems, with positive and negative feedback loops is essential to understanding environmental problems and solutions. Critical thinking, evaluating data, and formulating hypotheses are skills that allow students to understand the conflict of opinions on environmental issues.

Topics and Key Concepts

While material covered in Chapter 2 will not be tested directly on AP Exam, an understanding of these foundational concepts will improve your performance in this Environmental Science course.

- Organize the steps of the scientific method. Discriminate between a hypothesis and a scientific theory.
- Differentiate between accuracy and precision.
- Compare deductive and inductive reasoning and cite a specific example of each.
- Generalize the types of models available for scientific study.
- Differentiate between open and closed systems, and cite examples of each.
- Define and describe negative feedback and positive feedback.
- Reason why homeostasis is a combination of negative and positive feedback loops. Postulate an explanation of why a moderate disturbance may help maintain homeostasis.
- Evaluate the difference between scientific consensus and conflict.

Key Terms

blind experiments	emergent properties	natural experiment	science
closed systems	homeostasis	negative feedback	scientific consensus
controlled study	hypothesis	open systems	scientific theory
deductive reasoning	independent variable	paradigm shifts	significant number
dependent variable	inductive reasoning	positive feedback	state shift
disturbances	manipulative	replication	systems
double-blind	experiments	reproducibility	throughput
experiments	models	resilience	

Pacing Guide

3-5 days should be spent on this chapter. While this chapter contains little content directly tested on the AP exam, its coverage of experimental design is crucial. If you find that the students are weak in the concept of experimental design, you may want to include more experimental design throughout the course and incorporate it into laboratory activities, particularly inquiry based lab activities.

Approach and Tips

As overdone as it may seem, take the time to review experimental design and setup. Use of the scientific method is key to AP Environmental Science. Having students plan, design and implement experiments are major tasks that all students need to know. If possible both natural experiments as well as manipulated experiments should be included. Too often, students are given “cookbook-type” laboratory exercises in class and are unable to use a piece of information to design a workable laboratory experiment. Students should be able to write hypotheses based on observations. The easiest way for students to write a hypothesis statement is to use a simple if/then statement. Planning a single variable experiment is vital for success on the AP exam. Emphasize the importance of having a control and constants for all the other factors which are components of the experiment. Make sure students understand why they should test only one variable at a time and have multiple, identical setups with sufficient numbers of test subjects, so that a hypothesis can be verified using statistics.

For many students, the difference between the independent and dependent variables remains unclear. Continued practice on graphing and interpreting of graphs and charts, along with designing experiments, should make the distinctions clearer throughout the year. Ensure that you explain why the dependent variable is graphed on the y-axis and independent on the x-axis.

Systems are interactive relationships involving many different factors (resources). Systems and homeostasis are important when talking about ecosystems. Use examples of both positive and negative feedback loops to indicate how a system may change. Remember that a positive feedback loop increases change whereas a negative feedback loop decreases the change. Students will struggle with these concepts. Keep reminding them that negative feedback minimizes the deviation from normal, while positive feedback moves further away from normal conditions. Examples of disturbances, such as a forest fire, can be used to explain the concept of resilience.

Have students practice calculating percentages. Remember, on the AP exam the use of calculators is not permitted. By having students perform this operation frequently, they will have no difficulty when taking the exam. You will not need to memorize conversions between metrics or SI units and U.S. units, however it is recommended that you know the metric prefixes from giga through pico and how to convert between them using dimensional analysis. Another weakness is the use of scientific notation. Make sure students get as much practice as possible doing calculations involving scientific notation without a calculator. Working with fractions, using dimensional analysis (factor labeling)is also necessary for the AP exam. Practicing both of these skills throughout the year is necessary for students to do well on the exam.

Use current articles and scientific research to illustrate the concept of biasness in reporting. Stress the need for scientists to be objective and rational. Thinking critically and knowing the sources of data are two vital components of good scientific decisions. Have students analyze information keeping in mind who stands to gain.

Common Mistakes and Misconceptions

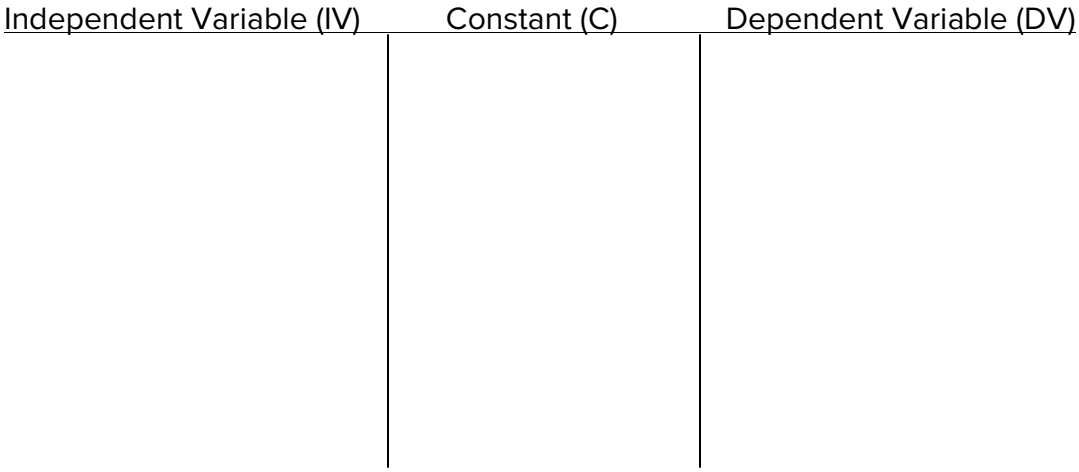
The most common mistake that students make in this chapter is the reversal of positive and negative feedback loops. They need to remember that positive adds to the situation or problem, while negative usually stabilizes or takes away from a system. Another area that students need to know is how to formulate a hypothesis. When the AP exam includes an experimental design question, a hypothesis is always a required element. The experiment needs to have a reasonable, testable hypothesis based upon the stated observation. Only one variable should be changed to create a controlled experiment. Although students

have been taught the scientific method in various science courses, you may find that they actually struggle setting up a controlled experiment with a single quantifiable variable.

Activities

Experimental Design Activity

A good way to teach experimental design is have students do a formal lab write-up template that they can use for every lab this year. Teach them to make this chart at the beginning of the year and have them use it on all lab reports. The chart is a tool to help students visualize and organize their thoughts about the experiment. The chart looks like this:



Have the students design an experiment to test the effect of a certain concentration of a chemical on mealworms. You can do this as a demo or have students work in lab groups. Obtain mealworms, cornmeal, and a container with a lid. Have the students brainstorm about what things are constant. In this experiment, examples of constants would be the mealworm, the container, the cornmeal, etc. Next, teach the students that the independent variable is the part of the experiment that you are testing. Suppose the student wanted to test how caffeine would affect his/her mealworm. In this experiment, the independent variable would be the caffeine. Finally, have the students fill out the dependent variable. The dependent variable is your measurable result. In this experiment, one result could be that the mealworm will die. The student is making a prediction. The tested results may not agree with the prediction, but that is the

point of the scientific method: to follow the steps of discovery and state in your conclusion what the experiment showed. Here is an example of what the student's chart in this example would look like:

Independent Variable (IV)	Constant (C)	Dependent Variable (DV)
Caffeine concentration	mealworm cornmeal container	death

Evaluating Sources of Data/Critical Thinking Activity

Give the students a topic that they think they know. An example is global climate change. Tell them to research the topic on the internet finding 5 -10 sources of information/data. Have them respond to the questions on the worksheet located at the end of this teacher's manual chapter.

Questions for Review

1. What steps are taken to formulate and test a hypothesis?
   The steps to formulate and test a hypothesis are: identify a question, form a testable hypothesis, collect data to test the hypothesis, and interpret the results. If the hypothesis is rejected reformulate another testable hypothesis. Consulting prior knowledge should also be a part of any experimental design.

2. How can statistics be used to understand data from an experiment? Can statistics be used to skew data? Explain.
   Statistics can help interpret results of an experiment. Quite frequently probability and degree of confidence can be calculated to determine amount of variability or occurrences by chance. Some statistical tests require that data meet certain parameters. If these tests are applied in the wrong situations, results can be skewed or invalid.

3. Why are most models mathematical expressions? What is an example of a model and what is its significance?
   Models can be used to gather information about environmental systems. Mathematical models allow researchers to manipulate variables without destroying any ecosystems and/or organisms in the process. A simple population growth model is $N_t = rN_{(t-1)}$. *It is useful because it describes a relationship between population size and growth rate. In addition, it enables predictions for populations over time. It allows researchers to investigate population sizes and growth rates across multiple generations in very little time.*

4. A forest is ravaged by a fire but re-growth is evident in the years that follow. What terminology from the chapter can explain the events that have occurred in this ecosystem?
   The fire depicts a disturbance while the forest re-growth establishes the resilience of the ecosystem.

Practice Questions

Multiple Choice:

Directions for questions 1-5: The lettered choices below correspond to the descriptions given in questions 1-5. Select the one lettered choice that best fits each statement. Each choice may be used once, more than once, or not at all.

(A) model
(B) manipulated experiment
(C) natural experiment
(D) blind experiment
(E) control

1. observational experiment of natural events

2. experimental test group is unknown

3. often a mathematical equation

4. an experiment in which conditions are deliberately altered

5. $N\ t = rN_{(t-1)}$

Directions: For each of the following questions, select the one lettered choice that best answers the question.

6. In the environment, a network of interdependent components and processes, with materials and energy flowing from one component to another is called a(n) _____.
   (A) ecosystem
   (B) niche
   (C) habitat
   (D) environmental condition
   (E) population

7. Which of the following is **NOT** an anthropogenic disturbance?
   (A) severe drought in a grassland biome
   (B) agricultural crop production
   (C) forest fire started by a cigarette butt
   (D) eutrophication caused by fertilizer runoff
   (E) damming a river for hydroelectric power

Use the following description for questions 8-10.

Cindy and Bob want to investigate the role of fertilizer on the growth of plants. They set up an experiment with bean plants. Bob decides to keep the amount of water and light constant. They use varying amounts of fertilizer and monitor the growth of the plants.

8. What is the independent variable?
   (A) plant growth
   (B) amount of fertilizer
   (C) the bean plants
   (D) water
   (E) light

9. Identify the dependent variable.
   (A) light
   (B) water
   (C) plant growth
   (D) the bean plants
   (E) amount of fertilizer

10. Identify the control for this experiment.
   (A) the plant with no fertilizer
   (B) the plant with the least amount of fertilizer
   (C) the light and water
   (D) the bean plants
   (E) the plant with the most fertilizer

Free-Response Question:

Directions: Answer all parts of the following question. Where explanation or discussion is required, support your answers with relevant information and/or specific examples.

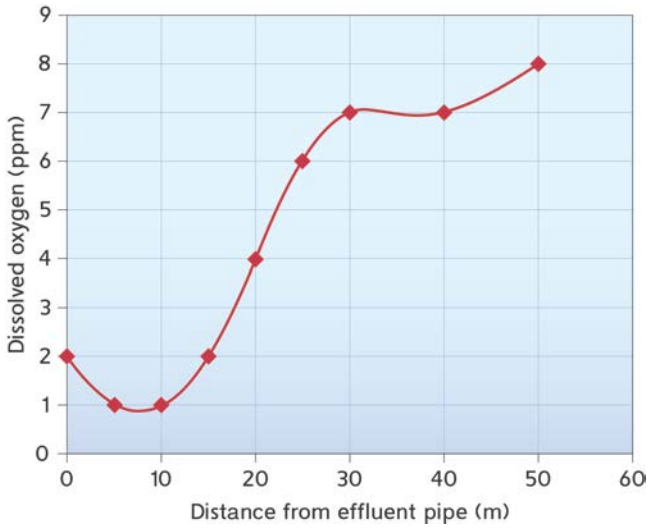
1. Aquatic and terrestrial ecosystems have many abiotic (non living) components. The organisms within each ecosystem have very specific requirements for life and these abiotic components are limiting factors for populations.

   (a) Describe **two** abiotic components of an ecosystem.

   (b) Design a controlled experiment to test one of the abiotic components you described in part (a).

      (i) Be sure to formulate a testable hypothesis.
      (ii) Identify the independent and dependent variable.
      (iii) Explain the procedure including plans for data collection.
      (iv) Describe possible results from your experiment.

   (c) The following graph shows water samples in a stream taken at various distances (x- axis) from a sewage treatment effluent pipe and the level of dissolved oxygen (y-axis). The normal DO for this stream is 10 ppm.



      (i) Describe the general trend of the graph.
      (ii) What percent of the normal DO is the value at 0 meters from the pipe?
      (iii) What does this data suggest about natural ecosystems?

Answers to Practice Questions

Multiple Choice:

1. C
2. D
3. A
4. B
5. A
6. A
7. A
8. B
9. C
10. A

Free-Response Question:

This question is based on 11 points. The students can only score a maximum of 10 points.

1. (a) 2 points total. One point for each abiotic factor given. Only the first two will be scored. Such factors include, but are not limited to, temperature, pH, dissolved oxygen, precipitation, nitrates.

   (b) (i) 1 point for a testable hypothesis

   (ii) 2 points total. 1 point for correctly identifying the dependent variable and 1 point for correctly identifying the independent variable.

   (iii) 2 points total. 1 point for giving a feasible procedure and 1 point for giving a data collection method that includes time.

   (iv) 1 point for describing a possible result.

   (c) (i) 1 point for giving the trend, a decrease and then a continual increase.

   (ii) 1 point for calculating the %

   2/10 x 100 = 20%

   (iii) 1 point for stating that natural ecosystems tend to recover over time or have resilience.

Answers to questions in the Student Edition:

Case Study AP Document-Based Question (page 34)

(A) Answers should include some of the following but are not limited to:
   a. Pros of doing laboratory studies include: being able to control for multiple variables, having complete control over the environment of the study, having a stable condition throughout the experiment, and being able to manipulate the environment to possible futuristic conditions.
   b. Cons of doing laboratory studies include: oftentimes laboratory studies are limited in looking at the interactions between species, laboratory studies do not vary as much as the real world so it can be hard to extrapolate laboratory results to actual environments, laboratory studies are often limited by space, and laboratory studies may not effectively imitate the environment which can give misleading results.

(B) Answers should include some of the following but are not limited to:
   a. Pros of conducting field studies include: field studies can have the natural variation that species experience in the wild (can be a pro or a con), long term observational field studies can give very informative results, and interaction between species can be observed in their natural environment.
   b. Cons of conducting field studies include: manipulations can be limited to currently naturally occurring conditions, field studies can have the natural variation that species experience in the wild, field studies cannot control for uncommon conditions, and the logistics of conducting field studies can be difficult.

AP Connections Review Answers (pages 45-47)

Multiple-Choice

1. a. The definition of hypothesis is a testable explanation for an observation.

2. b. These model are built on simulations with different responses to variables, and so can vary widely. This is why multiple climate models are needed to have confidence that overall predictions are reliable.

3. a. The scientist was using inductive reasoning by applying the scientific method. She gathered data based upon observation and repeated the experiment in four different fields for replication. She came to the general conclusion that the violet and yellow flowers were favored, thus was using inductive reasoning.

4. d. Because the toxicologist treats one group of *Daphnia* with lead and compares the results to another group of *Daphnia* not exposed to lead, this is a controlled experiment. The botanist did not have a control, nor did the zoologist. The toxicity of pesticides should have been tested on numerous fish, but separately. The increased lung and liver cancers may not demonstrate the impact of smoking and drinking unless the results are compared to the results from people with those cancers that did not drink or smoke.

5. c. The clover must be helping to provide extra nitrogen to the soil, based on the enhanced growth of the rye grass.

Data Analysis and Free-Response Questions

1. 75 Quadrillion Btus
2. Pelts
3. $1,200 Billion. In 2020, the benefits are ~ $1,950 Billion. In 2000, they are $750 Billion. $1,950-750 = $1,200 Billion
4. Venezuela, at 18% of the global oil supply
5. Highest: 1,500 child deaths; Lowest: 0 child deaths. The lowest number might be misleading because of the scale of the graph. 0-50 child deaths could still look roughly like 0 child deaths at this scale, due to the higher values at lower values of HDI.
6. Leftmost: one species; Rightmost: 14 species

Evaluating Sources of Data/Critical Thinking Activity Worksheet

*Student:*_____

1. Summarize your findings.

2. Do you think global climate change is a problem that needs attention? Why or why not?

3. Using Table 2.2 Questions for Baloney Detection, in your textbook, put each source to the test and answer the questions in the table.

4. Do you agree or disagree with your original answer in question #2? Why or why not?