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ABSTRACT

This monograph presents a module that introduces Newtonian Mechanics and related Science - A Process Approach (SAPA) materials. The activities are designed to give the necessary background for understanding the physics involved with the SAPA exercises relevant to this topic. The module is designed so that it can be used with individualized format. It is not designed to be used on a completely independent basis. Three of the topics presented, Using Space/Time Relationships, Predicting, and Measuring, are taken directly from Science - A Process Approach/Part E. Other topics include Distance Measure, Volume Measure, Direction (Vectors), Force, and Momentum. Each laboratory experience is presented in such a way to include objectives, procedures, materials needed and discussion and/or review questions. (EB)

NEWTONIAN MECHANICS FOR ELEMENTARY SCHOOL TEACHERS

By

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Foreword

This module introduces Newtonian Mechanics and related SAPA materials. The activities are designed to give you the necessary background for understanding the physics involved with the AAAS exercises which are keyed to this topic. In some activities you will be directly using AAAS booklets, equipment and worksheets. This should give you confidence with the AAAS materials.

The module is designed so that it can be used with individualized format. You have the objectives, related AAAS exercises and activities. You will probably find that this booklet does not supply adequate equipment instructions in all cases. It is not designed to be used on a completely independent basis. You will need teacher guidance for both equipment and graphing problems as you work through this booklet. You may do the exercises at your own rate. The instructor will occasionally call a small group together for a discussion of the exercises. Make sure that you see the instructor a minimum of once per activity.

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RELATED SAPA EXERCISES AND OBJECTIVES

1. Part A,g: recognizing direction

   Objectives applicable to adults: none.

2. Part A,h: observing movement

   Objectives applicable to adults: none.

3. Part A,k: comparing lengths

   Objectives applicable to adults:

   a. ordering objects by length from shortest to longest.

4. Part A,i: recognizing time intervals

   Objectives applicable to adults: none.

5. Part B,d: linear measurement

   Objectives applicable to adults:

   a. state the results of a measurement when the measurement is not the exact number of units used as your standard.

6. Part B,j: comparing volumes

   Objectives applicable to adults:

   a. order containers by volume, when ordering is not obvious by inspection, by pouring liquid or a finely divided solid (such as sand) from one container to another;

   b. demonstrate the comparison of volume of containers by determining how many unit volumes are required to fill each of them.

7. Part B,l: linear measurement using metric units

   Objectives applicable to adults:

a. state the names of three metric units of linear measure -- the centimeter, the decimeter, and the meter;

b. state measurements as being between two numbers, and name the unit used;

c. Demonstrate the approximate length of a centimeter, a decimeter, and a meter.

8. Part B,n: making comparisons using a balance

Objectives applicable to adults:

a. order objects the weight of which differ by lifting them and by comparing them on an equal arm balance;

b. state a rule that one object is heavier than another because the earth-pull on that object is greater than it is on the other;

c. demonstrate how to compare the weight of small objects by counting the number of arbitrary units, such as paper clips, pins, or tacks, needed to balance the objects on an equal arm balance;

d. describe the results of his measurements, as in the following example: "the object weighs the same as six paper clips" or "the object weighs more than ten paper clips but less than eleven paper clips".

9. Part B,t: time intervals

Objectives applicable to adults:

a. distinguish short time intervals involving minutes or seconds by counting, or by using a time measuring device such as a metronome, pendulum, water clock, or sandglass timer;

b. state observed differences in time intervals.

10. Part B,x: observing collisions

Objectives applicable to adults:

a. identify the heavier object as the one which exerts a greater force when two objects move at the same speed;

b. identify the lighter object as the one which will move farther, given two objects of different weights and the same force exerted on each;

c. demonstrate a procedure for measuring and recording changes in the position of various objects.

11. Part C,d: telling time

Objectives applicable to adults: none.

12. Part C,e: observing animal motion

Objectives applicable to adults:

a. describe the "push" common to animals that walk or crawl.

13. Part C,f: measuring forces with springs

Objectives applicable to adults:

a. demonstrate or describe use of equal arm balance;

b. state that if an object does not move, the forces acting upon it must be in balance;

c. construct a graph and describe precisely how attaching a weight to a spring increases the force stretching the spring.

14. Part D,d: dividing to find rates and means

Objectives applicable to adults:

a. apply a rule to determine the speed, given the distance and time.

15. Part D,f: describing the motion of a revolving phonograph record

Objectives applicable to adults:

a. describe and demonstrate how to measure the rate of revolution of a revolving disc in revolutions per unit time (for example, revolutions per minute);

b. describe and demonstrate how to measure the rate of revolution (in rpm) of objects located at different distances from the center of a disc;

d. describe and demonstrate how to measure the distance an object moves per unit of time when it is at different distances from the center of a revolving disc;

e. describe and demonstrate that the farther an object is located from the center of a revolving disc, the greater is its linear speed, although its rate of revolution is the same.

16. Part D,j: describing locations

Objectives applicable to adults:

a. identify the positions of a number pair on a graph or a grid.

17. Part D,o: rate of change of position

Objectives applicable to adults:

a. state and apply a rule that the speed of an object is the distance moved per unit of time;

b. distinguish between speed, time taken to change position, and distance moved.

18. Part D,p: describing and representing forces

Objectives applicable to adults:

a. construct vectors to represent forces;

b. describe changes in motion related to forces;

c. identify the forces causing motion, or lack of it in simple situation.

19. Part D,u: relative position and motion

Objectives applicable to adults:

a. describe observed changes in the position of objects relative to the position of another observer.

20. Part D,v: observing falling objects

Objectives applicable to adults:

a. distinguish whether or not two objects dropped from the same height and at the same time strike the floor at the same time;

b. identify possible causes of observed differences in falling times of objects that do not strike the floor at the same time when dropped simultaneously from the same height.

21. Part E,o: precision in measurement

Objectives applicable to adults:

a. Describe a procedure for finding a range of measurements;

b. Identify the median as a representative number for a set of measurements.

22. Part E,r: force and motion

Objectives applicable to adults:

a. construct or identify a force diagram to illustrate that an unbalanced force is acting on a body that is changing speed;

b. construct or identify a force diagram to illustrate that only balanced forces are acting on a body at rest;

c. interpret graphs to show that the greater the force the greater the acceleration, (F∼a) F = ma, and the greater the mass (constant F), the less the acceleration.

23. Part E,s: a unit of force

Objectives applicable to adults:

a. construct or describe a calibration of a spring scale by measuring the elongation of the spring when objects of known weight are attached to the end of it;

b. apply a rule to measure an unknown force and apply the measurement in the standard metric unit of force, the Newton.

24. Part E,r: prediction in various physical systems

Objectives applicable to adults:

a. describe predictions and tests of his predictions using graphs;

use with spring (stretch and vibration) and pendulum.

25. Part E,t: rotation and linear speed

Objectives applicable to adults:

a. apply a rule for finding the distance a wheel rolls, given the circumference of the wheel and the number of rotations it makes;

b. apply a rule for finding the linear speed of a rolling wheel given its angular speed and its circumference or diameter.

Topics		Activities
A.	Distance measure	2
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J.	Momentum	8

PARTICIPANT OBJECTIVES

1. Measure distances in the metric units.
2. Identify and describe time intervals in your own units (operationally define time).
3. Identify the definition of average linear speed.
4. Describe how to graph distance and time data.
5. Describe angular speed.
6. Apply a rule for finding the linear speed of a rolling wheel given its angular speed and its circumference or diameter.
7. Identify the definition of acceleration $a = \frac{V_2 - V_1}{T}$.

8. Describe how to identify the qualitative acceleration shown in a line graph of speed and time.
9. Describe how to guess if object is accelerating for a distance vs. time graph.
10. Identify the forces on an object by constructing a force diagram on the object or identifying the proper force diagram.
11. Identify or construct force diagrams for balanced and unbalanced force situations (balances, carts, springs).
12. Interpret a graph of force vs. acceleration to tell what happens to acceleration as force increases.
13. Construct or identify a graph of force on a spring (weight) vs. stretch of the spring.
14. Use the graph of 13 to describe the calibration of a spring scale and predicting future points (extrapolation and interpolation).
15. Apply a rule to measure an unknown force on your spring and apply the measurements in the standard unit of measurement, the Newton.
16. Describe the accuracy of measurements using the range and median.
17. Describe predictions and tests of his predicting using graphs.
18. Identify momentum.
19. Apply a rule to measure the volume of a solid by water displacement.

LEARNING ACTIVITIES

1. Time, measurement in arbitrary units:

   Pendulum, ticker tape timer, water clock, blinky, clock

   (Objectives 2, 16, 17)

2. Linear Motion

   a. uniform: baby bulldozer

   b. non-uniform: pulling tickertape with hand

   (Objectives 1, 2, 3, 4, 7, 8, 9, 16, 17)

3. Rotational Motion

   Angular and linear speed of a rolling wheel

   Use SAPA Part E,t

   (Objectives 1, 2, 3, 5, 6)

4. Vectors: relative motion, direction

   Prerequisite information for forces

5. Analysis of balanced forces

   a. weighing unknown with pan balance

      use SAPA Part E, f; project a

   b. lever concept

      use SAPA Part E, f; project b

      (balance lever at different distances from center of fulcrum)

   (Objectives 10, 11, 17)

6. Spring calibration for definition of Newton, Hooke's Law.

   Graphic analysis of spring stretch and force use SAPA, Part C,f;projects a and b and Part E,s (Activity 2)

   (Objectives 10, 11, 14, 15, 16, 17)

7. Force vs. acceleration - carts and rubber bands or weights

   (Objectives 10, 11, 12, 16, 17)

8. Momentum: film loop trains
(Objective 18)
9. Measuring volume of a solid by water displacement
(Objective 19)

LABORATORY EXPERIENCE I: TIME

In this experience you will practice taking data, organizing data, setting standards, and determining uncertainty of measurement. This experiment will explore various operational definitions of time. (An operational definition is one that is useful in measurement.) Time is a very basic (and difficult) concept. We are not going to answer the following questions. What is time? Does time exist? What is the direction of time? These questions are still unanswered and are today being considered by theoretical physicists.

Each table will have four devices that may be used to tell time.

1. pendulum
2. water clock
3. heart (yours)
4. bell timer

The clock on the wall can also be used to tell time.

Questions

1. How can you tell "time" with each device? Take measurements with each device.

2. What units of measurements can you use: Do you need seconds?

3. Set a standard. All time measures should be made using your standard timing device. Does it have to be the clock? Give reasons why you chose your standard. Could you use another standard?

4. Take measurements of time with all the devices using your standard. Organize your data in tabular form with units. Use your own units. Is your choice of units important if you are consistent?

5. What is your error in measurement? Why? Can you give a number stating your error? Example. 10 sec. ± .5 sec. This is one good way of stating an error.

LABORATORY EXPERIENCE II: LINEAR MOTION

Introduction:

In this experience you will be studying the motion of two different objects, one traveling at a constant speed and one whose speed is changing. You will be able to apply the definition of speed = $\frac{\text{distance}}{\text{time}}$

$$V = \frac{\text{distance}}{\text{time}}$$

by measuring the distances an object travels in different times. You will gather distance and time data, make the appropriate tables and construct graphs from these tables.

Experiment:

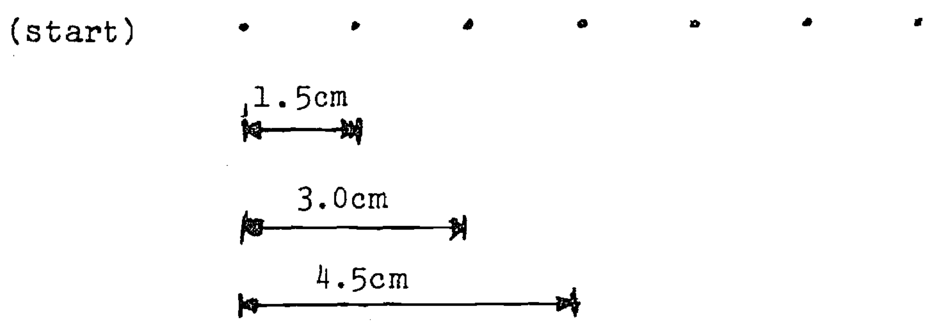
The definition of speed is the distance an object travels per unit time.

$$V = \frac{d}{t}$$

Part I - Constant speed

You will be given a baby bulldozer, a blinky and a camera and will take a picture of the baby bulldozer as it travels across the table. Your picture will look similar to figure 1.

FIGURE I



As the speed equals the distance/time, you can measure the distance between the starting point and the first dot and divide by the time interval (one dot of time) to get the average speed for the interval. You follow the same procedure for each interval:

EX.: first interval $\frac{1.5\text{cm}}{1\text{ dot}} = 1.5 \ \frac{\text{cm}}{\text{dot}} = \text{speed}$

second interval $\frac{3\text{ cm} - 1.5\text{ cm}}{2\text{ dots} - 1\text{ dot}} = 1.5 \ \frac{\text{cm}}{\text{dot}}$

third interval $\frac{4.5\text{ cm} - 3\text{ cm}}{3\text{ dots} - 2\text{ dot}} = 1.5\text{ cm/dot}$

Note that the average speed for the first interval, second interval and third interval is the same.

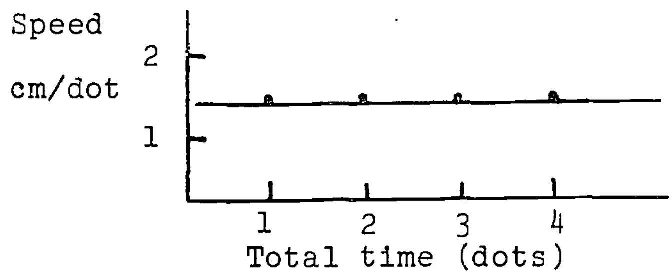
(1) Now measure your photograph and place in tabular form.

EX.:

Total time (dots)	Time interval	Average speed cm/dot
0	0	0
1	First	1.5
2	Second	1.5
3	Third	1.5

(2) You now can graph your data:

EX.:



Notes: A graph of speed versus time that is horizontal (slope - 0, see below) says that the speed stays the same or is constant.

Do you have error in your measurements?

How do you write it?

<u>Error</u>: If you measure 2 cm on your ruler you can really only measure to the nearest 1/2 mm. Thus you do not know if your measurement is 2.0 cm, or 2.05 cm or 1.95 cm. Therefore you write the error of a measurement 2.0 cm ± .05 cm.

(3) Write an error for each measurement.

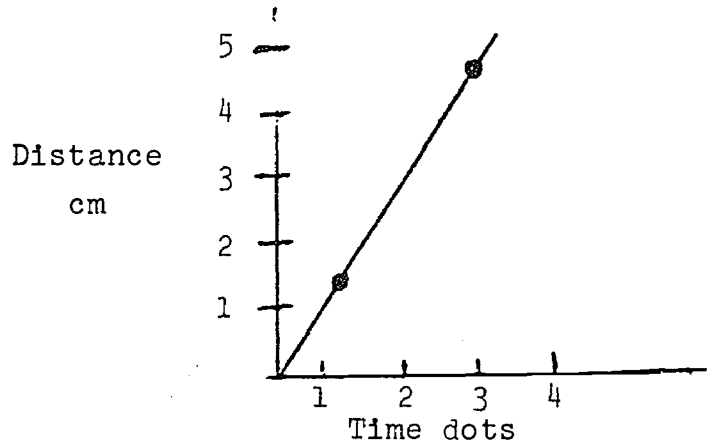
There is another way to place the data in FIGURE 1 in table form. You can record the total distance and total time.

EX.:

Distance (cm)	Total time (dots)
0	0
1.5	1
3	2
4.5	3

(4) Tabulate your data in this form.

One can make a distance versus time graph from this data.

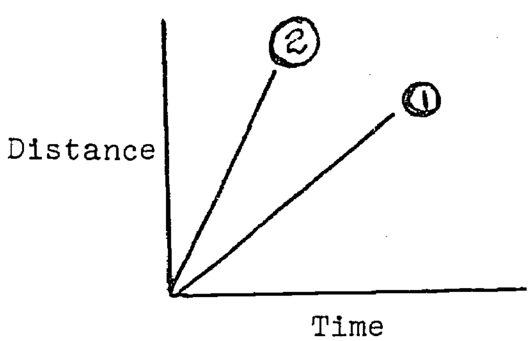


Note that this data shows a straight line. Any time you get a straight line from a distance versus time graph you have a constant speed. (Note the difference between the speed vs. time graph and distance vs. time graph.)

There is a term that describes straight lines that are at an angle. It is called SLOPE. The larger the angle of the line the larger the slope. THE SLOPE OF A DISTANCE VERSUS TIME GRAPH IS THE SPEED!!!

Which graph has the largest slope?
the largest speed?
Why?

The slope of your speed vs. time graph may have been zero.
Was it?



(5) Make a distance versus time graph of your data.

(a) Is it almost a straight line?

(b) Is the speed constant?

(c) Sketch a line on your graph showing a slower baby bulldozer.

(d) What could your graph look like if the speed was not constant?

Part II - Changing speed

Here you pull a piece of white ticker tape through a bell timer that is attached to a battery. You will give it a yank so that its speed will be changing.

(1) Make a distance versus time table and graph. How does it differ from part I?

(2) Make a speed versus time table and graph. How does it differ from part I?

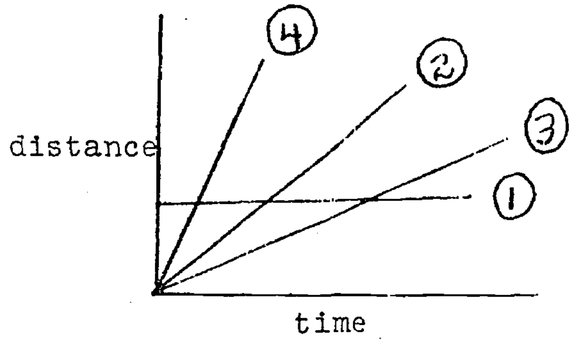
When an object changes speed it is said to be accelerating. Acceleration is the change in speed per unit time.

$$a = \frac{v_2 - v_1}{T}$$

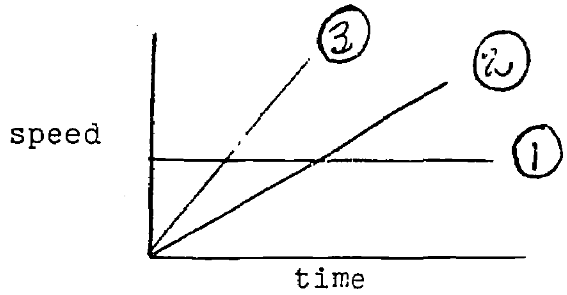
EX.: If you are going 30 mph and accelerate to 40 mph in one hour, then:

$$a = \frac{40 \text{ mph} - 30 \text{ mph}}{1 \text{ hour}} = 10 \text{ mph}^2$$

Which distance versus time graph shows acceleration



Which speed versus time graph shows acceleration? Which shows the largest acceleration?



LABORATORY EXPERIENCE III

ROTATIONAL MOTION

In this experience you will be studying rotational motion in a way similar to the methods by which you will introduce this concept to your students. You are provided AAAS booklet Part E, t, and the three worksheets that accompany the appropriate activities in this booklet. You are to do each activity outlined in the booklet and fill in each worksheet provided. See the instructor if you need help.

SCIENCE—A PROCESS APPROACH / PART E

USING SPACE/TIME RELATIONSHIPS 17

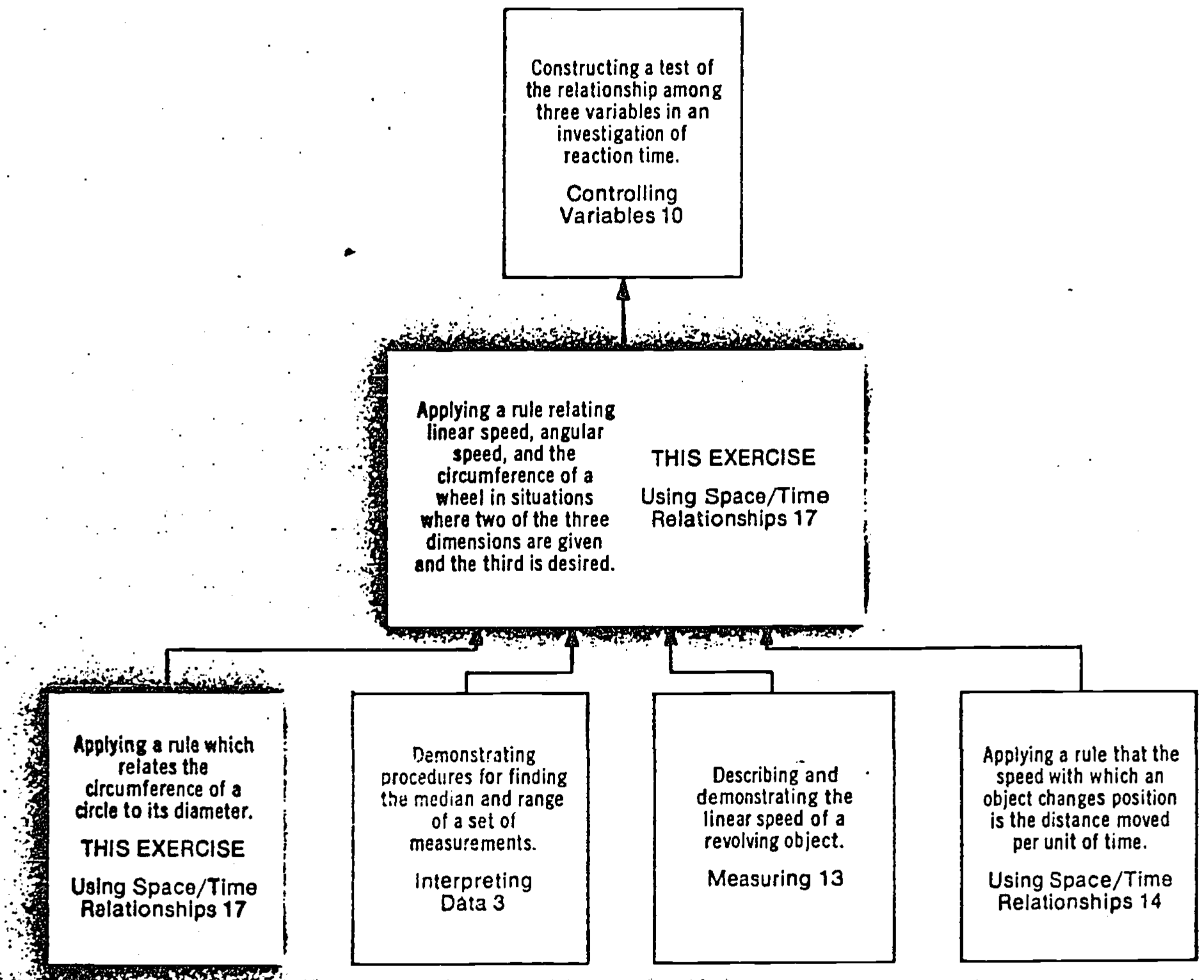
ROTATIONS AND LINEAR SPEED

OBJECTIVES

At the end of this exercise the child should be able to

1. *APPLY A RULE* for finding the distance a wheel rolls given the circumference of the wheel and the number of rotations it makes.
2. *APPLY A RULE* for finding the linear speed of a rolling wheel given its angular speed and its circumference or diameter.
3. *STATE* and *APPLY A RULE* relating the circumference and the diameter of a circle.

SEQUENCE



RATIONALE

In *Describing the Motion of a Revolving Phonograph Record, Measuring 13, Exercise f,* Part D, the children found that objects farther from the center of rotation travel faster (that is, with greater linear speeds) than those closer to it. Then, in *Rate of Change of Position, Using Space/Time Relationships 14, Exercise* o, Part D, they identified rate of change of position with linear speed. You may need to review some of the activities in these exercises, to be sure that the children can measure time and distance traveled and can compute linear speed.

The children should also be able to time and count rotations. They should state angular speeds as so many rotations in a unit of time: for example, one rotation per second or 60 rotations per minute.

In this exercise, the children will learn the relationship between the diameter and circumference of a circle. They will find that the distance a wheel moves as it rolls without slipping is equal to its circumference times the number of rotations. By measuring the number of rotations a rolling wheel makes in one minute, they will find the relationship between angular speed and linear speed.

In some fields of science, the words *rotation* and *rotate* are commonly used to describe the motion of an object spinning about an internal axis, whereas the words *revolution* and *revolve* are used to describe the motion of an object that moves about an axis external to itself. Thus, astronomers say, "The earth *rotates* on its axis once in 24 hours," and "The earth *revolves* around the sun once a year." However, both scientists and laymen frequently use these words interchangeably.

VOCABULARY

angular speed
linear speed
diameter
circumference
rotation (or revolution)

RELATED MATERIALS

Listed below are the materials required to conduct this exercise.

Some items cannot be supplied at all or are not supplied by Xerox in the Standard Kit. These are designated as *NS*. Note, however, that many of these items are supplied in the Comprehensive Kit. These are designated as *COMP*. A separate list of these items is included with the comprehensive materials.

It should be noted that some supplied items are expended in the course of this exercise. These expendable items are designated as *EXP*.

Some of the items used in several exercises and items too large for the Exercise Drawer will be found in the Teacher Drawer and are designated as *TD*.

Round object 30 centimeters or more in diameter, 1 (NS, COMP)
Metersticks, 4 (TD)
Power-driven wheels with battery and motor, 1
Power-driven wheels with battery and motor, 3 (NS, COMP)
Pair of smaller size tires, 1
Pairs of smaller size tires, 3 (NS, COMP)
Data sheet (as in Figure 2), 30 copies (EXP)
Pair of larger size tires, 1
Pairs of larger size tires, 3 (NS, COMP)
Alligator clips, 4 (found in Exercise "i" drawer)
Sixty-second interval timer, 1 (NS, COMP, TD)
Data sheet (as in Figure 3), 30 copies (EXP)
Assorted jar covers (NS)
Masking tape, 1 roll (NS)
Data sheet (as in Figure 7), 30 copies (EXP)
Bicycle (Optional.), 1 (NS)
Toy car, 1 (NS, COMP)
Pupil *Group Competency Measure*, 30 copies (EXP)

INSTRUCTIONAL PROCEDURE

Introduction

Show the class a bicycle wheel, or another round object 30 centimeters or more in diameter. A round wastebasket is also suitable. Tell the class that you are going to have a guessing game—one team against another. You want them to guess the distance, in centimeters, around the wheel or the top of the object. Have each child write his guess on a piece of paper. Then collect these papers, and list the guesses on the chalkboard: those of one team in one column and those of the second team in another. Determine a representative number for the guesses (the median or the mode, and the range) for the two teams, and keep a record of them so you can use them in *Activity 4*.

Ask or tell the children the name for the distance around a circle *(circumference)*. Write this word on the chalkboard, and have the children repeat it.

Explain that after they learn more about circles and circumferences, they will get another chance to guess the circumference of the bicycle wheel, or wastebasket. Then they will find out which team is closer to the correct answer. If you used a bicycle wheel, tell the children that you will want them to think about how far the bicycle moves forward for one or many rotations of the wheel.

Activity 1—Angular and Linear Displacement

Activities 1 and *2* should be done by groups of three or four children. If you do not have enough equipment for the whole class to work at one time, let one group at a time do these activities while the rest of the class is doing something else.

Give each group of children one centimeter ruler (or one meterstick) and one pair of power-driven wheels with the battery and motor removed. (See Figure 1.) Also, give them one pair of tires. Have the children tape a small piece of white paper (or make a chalk mark) near the rim of one wheel, so that they can observe the number of rotations it makes.

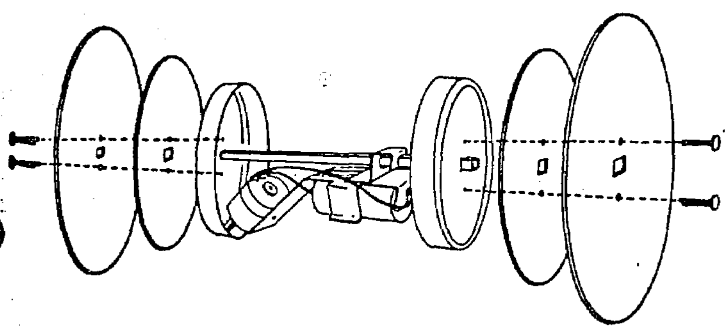


FIGURE 1

Give each child a copy of the data sheet, *Circumference of a Wheel and the Distance Traveled.* (See Figure 2.) First, let the children become familiar with the wheels, and then proceed with the activity as it is outlined on the data sheets. Help them if they have any difficulties, and discuss the results.

DATA SHEET

Exercise E — Circumference of a Wheel and the Distance Traveled

1. Use a string or strip of paper to measure the circumference of the wheel.
   The measure of the circumference is ______________ centimeters.
2. Predict how far the wheel will roll when it rotates once.
   The wheel will roll __________ centimeters in one rotation.
3. Check your prediction by rolling the wheel so that it makes one rotation.
   The wheel rolls ____________ centimeters.
4. Predict how far the wheel will roll when it rotates twice, then three times, and then five times.
   Two times: _____ cm
   Three times: _____ cm
   Five times: _____ cm
5. Check your predictions:
   Two times: _____ cm
   Three times: _____ cm
   Five times: _____ cm

Rule:
You can find the distance of roll for any wheel or circle by multiplying the number of rotations times the circumference.

Distance = number of rotations X circumference

6. Put one of the tires on each of the wheels. Roll the wheels along the floor or table top until they have made two complete rotations. Measure the distance rolled.
   The wheel rolled ______________ centimeters in two rotations.
7. Predict the circumference of the tire.
   It should be ______________ centimeters.
8. Measure the circumference to check your prediction.
   It is ______________ centimeters.

PART E

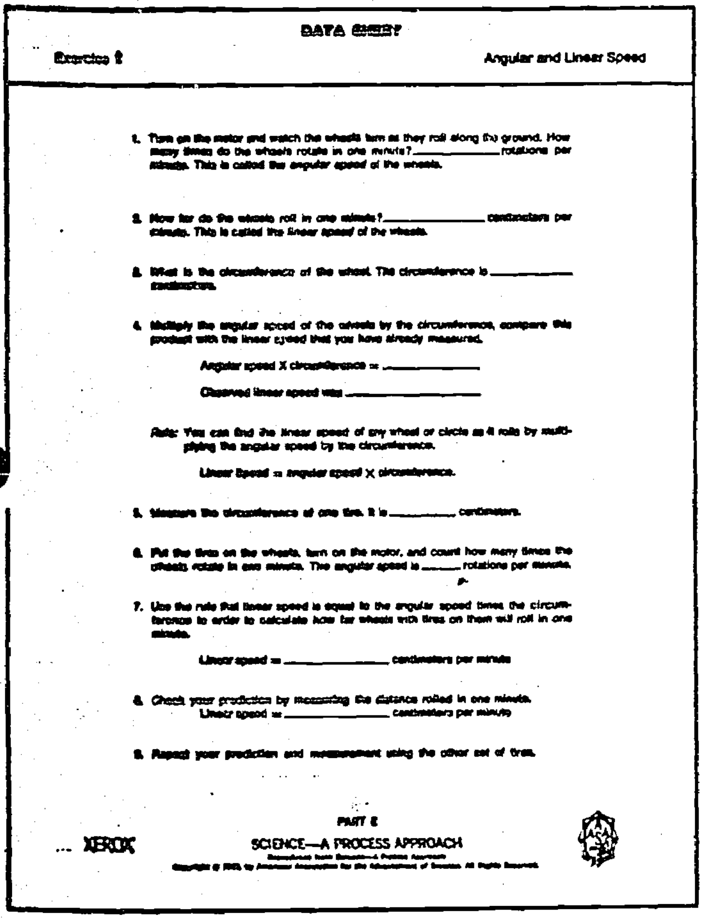
XEROX — SCIENCE—A PROCESS APPROACH

FIGURE 2

Activity 2—Angular and Linear Speeds

Give each group of children a pair of power-driven wheels and two pairs of tires. One pair of tires should increase the diameter of the wheels by about four centimeters; the other pair should increase it by eight centimeters. Each group should use the sixty-second interval timer or a watch with a sweep second hand. Show the class how to make the connections to the dry cell holder with the alligator clip. Let the groups investigate the wheels freely for a few minutes, and then give each child a copy of the data sheet, *Angular and Linear Speeds*. (See Figure 3.)

When all of the children have completed the data sheets, discuss them with the class.


DATA SHEET

Exercise [illegible] — Angular and Linear Speed

1. Turn on the motor and watch the wheels turn as they roll along the ground. How many times do the wheels rotate in one minute? ________ rotations per minute. This is called the angular speed of the wheels.
2. How far do the wheels roll in one minute? ________ centimeters per minute. This is called the linear speed of the wheels.
3. What is the circumference of the wheel. The circumference is ________ centimeters.
4. Multiply the angular speed of the wheels by the circumference, compare this product with the linear speed that you have already measured.

   Angular speed X circumference = ________

   Observed linear speed was ________

   Rule: You can find the linear speed of any wheel or circle as it rolls by multiplying the angular speed by the circumference.

   Linear Speed = angular speed X circumference.
5. Measure the circumference of one tire. It is ________ centimeters.
6. Put the tires on the wheels, turn on the motor, and count how many times the wheels rotate in one minute. The angular speed is ______ rotations per minute.
7. Use the rule that linear speed is equal to the angular speed times the circumference in order to calculate how far wheels with tires on them will roll in one minute.

   Linear speed = ________ centimeters per minute
8. Check your prediction by measuring the distance rolled in one minute.

   Linear speed = ________ centimeters per minute
9. Repeat your prediction and measurement using the other set of tires.

PART E

XEROX — SCIENCE—A PROCESS APPROACH

[illegible]

FIGURE 3

Activity 3—Relationship Between Circumference and Diameter

Have each child bring from home a jar, a lid, a tin can, or some similar object that is circular and between 5 and 20 centimeters in diameter. Select two or three distances in the room for each child to measure. You might choose the length or width of a desk, the distance between two marks on the chalkboard, or the distance between two pieces of masking tape on the floor. Tell the children that you want them to measure these distances in two ways, using their circular object as the measuring stick.

If the children need help, tell them to measure each distance in the following two ways:

1. By using the object as a simple measuring stick, and seeing how many circles fit side by side in the distance to be measured.
2. By rolling the circular object along the distance to be measured, and seeing how many times it goes around as it rolls over the distance.

Have each child put a mark or a small piece of tape on the rim of his rolling object, so he will know when it has made one complete turn. Display the results on the chalkboard, as shown in Figure 4.

	Jim	Anne	Karen	
Desk Length	24 diameters 8 rotations	15 diameters 5 rotations	13 diameters 4 rotations	
Distance on Chalkboard	28 diameters 9 rotations	17 diameters 6 rotations	14 diameters 4 rotations	
Distance on Floor	37 diameters 12 rotations	21 diameters 7 rotations	19 diameters 6 rotations	

FIGURE 4

Discuss the results with the children until everyone agrees that the number of diameters in each distance is approximately three times the number of circumferences. This is true whether the circular object is large or small.

Ask, **Why were the numbers larger when the unit of measure was the diameter rather than the circumference?** (The circumference is a larger unit of measure.) **How much larger is it?** (The circumference is slightly more than three times as large as the diameter.) **How can you measure the number of diameters in a circumference?** Let the children try any of the methods suggested.

One way to make the measurement more precise is to cut a strip of paper long enough to reach around the circular object, then to cut off the end, so that the strip just reaches around and none is left over, and finally, to put the circular object on the strip and measure the length of the strip in diameters, as shown in Figure 5a. Figure 5b shows three strips marked in this way.

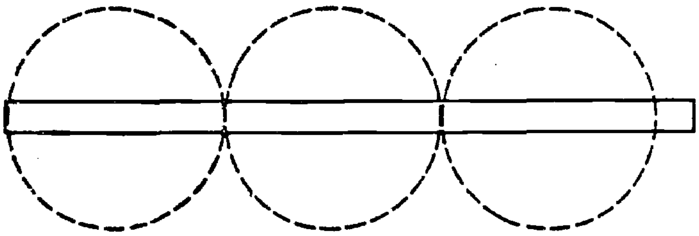


FIGURE 5a

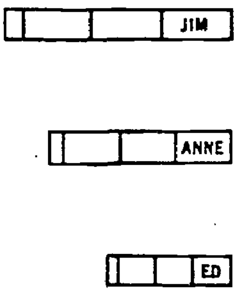


FIGURE 5b

Whatever method the children use, they should observe that the distance around the circular object (the circumference) is always just a little more than three times the distance across it (the diameter). Discuss this observation with the children, and summarize it by stating the relationship as a rule: The circumference of a circle is a little more than three times the diameter.

Activity 4—A More Precise Relationship Between the Circumference and Diameter

Tell the children that you want them to determine how much greater the circumference is than three diameters. Have each child examine the three diameters marked off on a length equal to the circumference, and suggest how he might describe the little bit that was left over. Tell the children to measure the length of the diameter to the nearest millimeter. Say, **If you divided the distance into ten equal parts, what would the length of each part be?** Then have them divide by ten. If the diameter of the circular object measures 70 millimeters, for example, then one-tenth of the diameter is 7 millimeters; if it is 65 millimeters, one-tenth of the diameter is between 6 and 7 millimeters, or 6.5 millimeters. Have the children mark off ten equal lengths along a diameter, as shown in Figure 6. The diameter then becomes a number line divided into tenths that the children can use to measure the "little bit left over" to the nearest tenth of a diameter.

When the children put the fractional part of the diameter along this scale, they should read the length of the circumference as between 3.1 and 3.2 diameters. If you wish, you may use *3.1* in stating the rule relating circumference and diameter. Emphasize that the relationship is true for circles of all sizes by referring to answers various children get using circles with different diameters.

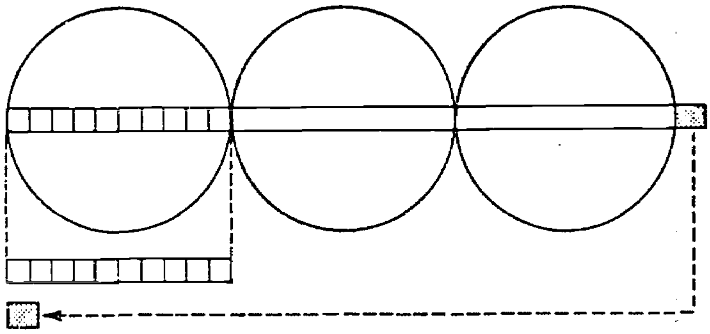


FIGURE 6

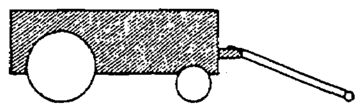
Now return to the question you raised at the beginning of the exercise. Have each child guess again the circumference of the bicycle wheel, or whatever object you used, and write his guess on a piece of paper. Do not give the children the diameter of the wheel. They should be able to estimate the circumference by first estimating the diameter. List the new estimates of each team on the chalkboard, and see what change there is in the median or mode and in the range. Have one or two children measure the circumference with a string and meterstick to determine which team came closer.

GENERALIZING EXPERIENCES (Optional)

1. Give each child a copy of the data sheet, *Comparing Angular Speeds of Two Wheels.* (See Figure 7.) As you read the questions to the class, emphasize that the diameters of the rear wheels are twice as long as the diameters of the front wheels. When the children have finished the data sheets, collect their papers and discuss their answers.
2. In the classroom, on the playground, or at home, have each child examine the wheels on his bicycle and measure the diameter of the front sprocket wheel, the rear sprocket wheel, and the tire. Ask the children to use these measurements to investigate the following questions, either by applying the rules they have learned in the exercise or by making measurements directly, or both. They will be able to answer some questions best by turning a bicycle upside down.
   a. How far will the bicycle roll if the wheel rotates once?
   b. How many times will the rear wheel rotate if the front sprocket (the pedals) makes one rotation?
   c. How far does the bicycle roll when the front sprocket makes one rotation?
   d. If the pedals move with an angular speed of one rotation per second, what will be the angular speed of the rear wheel?
   e. If the pedals move with an angular speed of one rotation per second, what will be the linear speed of the bicycle?

DATA SHEET

Exercise E — Comparing Angular Speeds of Two Wheels



The diameter of a rear wheel of this wagon is twice as long as the diameter of a front wheel.

1. If the diameter of a front wheel is 10 centimeters, what is the diameter of a back wheel?
   ____________ centimeters.
2. How far does the wagon move when the back wheels make one rotation?
   ____________ centimeters.
3. How far do the front wheels move when the back wheels make one rotation?
   ____________ centimeters.
4. How many rotations do the front wheels make when the rear wheels rotate once?
   ____________ times.
5. If the rear wheels make ten rotations per minute, what is the angular speed of the front wheels?
   ____________ rotations per minute.
6. If the rear wheels make ten rotations per minute, what is the linear speed of the wagon?
   ____________ centimeters per minute.

PART E

XEROX SCIENCE—A PROCESS APPROACH

[illegible]

FIGURE 7

GROUP COMPETENCY MEASURE

(Individual score sheets for each pupil are in the Teacher Drawer.)

TASK 1 (OBJECTIVE 1): The circumference of a wheel is 20 centimeters. How far will the wheel roll if it rotates two times?__________ centimeters.

Acceptable Behavior

The child records "40 centimeters."

TASKS 2, 3 (OBJECTIVE 3): How would you find the circumference of a circle if you know the diameter?

The diameter of the wheels on a particular cart is 3 centimeters. What is the circumference of the wheels?

____________ centimeters.

Acceptable Behavior

For Task 2, the child writes that the circumference is about three times as long as the diameter, or that the diameter should be multiplied by 3 or 3.1; for Task 3, the child records "9" or "9.3 centimeters."

TASK 4 (OBJECTIVE 2): Suppose that the wheel on the cart referred to in Task 3 rotates with an angular speed of 20 rotations per minute. What is the linear speed of the wheel as it rolls along the ground?______________ centimeters per minute.

Acceptable Behavior

The child records "180" or "186 centimeters per minute."

INDIVIDUAL COMPETENCY MEASURE

(Individual score sheets for each pupil are in the Teacher Drawer.)

TASK 1 (OBJECTIVE 1): Say, **The circumference of a wheel is twenty centimeters.** Ask, **How far will the wheel move if it rotates two times?**

Acceptable Behavior

The child says "40 centimeters."

TASK 2 (OBJECTIVE 3): Say, **How do you find the circumference of a wheel if you know its diameter?**

Acceptable Behavior

The child says that the circumference is three times as long (or a little more than three times as long) as the diameter, or that the diameter should be multiplied by *3* or *3.1*.

TASK 3 (OBJECTIVE 3): Give the child a pencil and a piece of paper. Show him a toy car whose wheel diameter you have measured. Say, **The diameter of the wheels on this car** (wagon) **is_______ centimeters.** Specify the number you have measured. **What is the circumference of the wheel?**

Acceptable Behavior

The child gives an answer that is between *3* and *3.1* times the diameter you have specified.

TASK 4 (OBJECTIVE 2): Say, **Suppose the wheel on the same car** (wagon) **rotates with an angular speed of twenty rotations per minute. What will be the linear speed of the car?**

Acceptable Behavior

The child gives an answer that is the product of *20* and the circumference he calculated in Task 3.

DATA SHEET

Exercise 1

Circumference of a Wheel and the Distance Traveled

1. Use a string or strip of paper to measure the circumference of the wheel.

   The measure of the circumference is ________________ centimeters.

2. Predict how far the wheel will roll when it rotates once.

   The wheel will roll _________ centimeters in one rotation.

3. Check your prediction by rolling the wheel so that it makes one rotation.

   The wheel rolls ___________ centimeters.

4. Predict how far the wheel will roll when it rotates twice, then three times, and then five times.
   Two times: _____ cm
   Three times: _____ cm
   Five times: _____ cm

5. Check your predictions:
   Two times: _____ cm
   Three times: _____ cm
   Five times: _____ cm

   Rule:

   You can find the distance of roll for any wheel or circle by multiplying the number of rotations times the circumference.

   $$\text{Distance} = \text{number of rotations} \times \text{circumference}$$

6. Put one of the tires on each of the wheels. Roll the wheels along the floor or table top until they have made two complete rotations. Measure the distance rolled.

   The wheel rolled ________________ centimeters in two rotations.

7. Predict the circumference of the tire.

   It should be ________________ centimeters.

8. Measure the circumference to check your prediction.

   It is ________________ centimeters.

DATA SHEET

Exercise 1 | Angular and Linear Speed

1. Turn on the motor and watch the wheels turn as they roll along the ground. How many times do the wheels rotate in one minute?____________rotations per minute. This is called the *angular speed* of the wheels.

2. How far do the wheels roll in one minute?______________ centimeters per minute. This is called the *linear speed* of the wheels.

3. What is the circumference of the wheel. The circumference is ____________ centimeters.

4. Multiply the angular speed of the wheels by the circumference, compare this product with the linear speed that you have already measured.

   Angular speed X circumference = ______________

   Observed linear speed was ____________________

Rule: You can find the linear speed of any wheel or circle as it rolls by multiplying the angular speed by the circumference.

Linear Speed = angular speed × circumference.

5. Measure the circumference of one tire. It is__________ centimeters.

6. Put the tires on the wheels, turn on the motor, and count how many times the wheels rotate in one minute. The angular speed is______ rotations per minute.

7. Use the rule that linear speed is equal to the angular speed times the circumference in order to calculate how far wheels with tires on them will roll in one minute.

   Linear speed = _______________ centimeters per minute

8. Check your prediction by measuring the distance rolled in one minute.

   Linear speed = _______________ centimeters per minute

9. Repeat your prediction and measurement using the other set of tires.

GROUP COMPETENCY MEASURE

Exercise t

TASK 1: The circumference of a wheel is 20 centimeters. How far will the wheel roll if it rotates two times?

_____________ centimeters.

TASKS 2, 3: How would you find the circumference of a circle if you know the diameter?

____

____

____

____

____

The diameter of a wheel on a particular cart is 3 centimeters. What is the circumference of the wheels ?

_____________ centimeters.

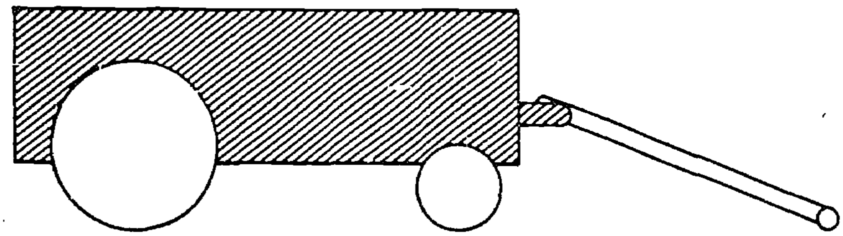
TASK 4: Suppose that the wheel on the particular cart (referred to in Task 3) rotates with an angular speed of 20 rotations per minute. What is the linear speed of the wheel as it rolls along the ground?

_____________ centimeters per minute.

DATA SHEET

Exercise 8

Comparing Angular Speeds of Two Wheels



The diameter of a rear wheel of this wagon is twice as long as the diameter of a front wheel.

1. If the diameter of a front wheel is 10 centimeters, what is the diameter of a back wheel?
   ______________ centimeters.

2. How far does the wagon move when the back wheels make one rotation?
   ______________ centimeters.

3. How far do the front wheels move when the back wheels make one rotation?
   ______________ centimeters.

4. How many rotations do the front wheels make when the rear wheels rotate once?
   ______________ times.

5. If the rear wheels make ten rotations per minute, what is the angular speed of the front wheels?
   ______________ rotations per minute.

6. If the rear wheels make ten rotations per minute, what is the linear speed of the wagon?
   ______________ centimeters per minute.

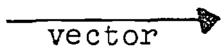
LABORATORY EXPERIENCES IV

VECTORS

You will not complete a laboratory experience here, but will read the following definition of a vector and apply it to the questions below. You will have an opportunity to draw "vector diagrams" in exercises 5, 6 and 7.

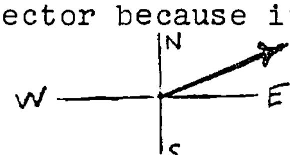
DEFINITION: A vector is a representation of any quantity that has magnitude (ex. size, length, a number) and direction.

You draw a vector by drawing a line a certain length to represent the vector's size and put an arrow on the end of the vector to show its direction.



vector

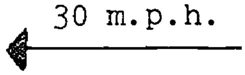
EXAMPLES: 1. I traveled 2 miles north east.
This is a vector because it has magnitude and direction.



The line is 2 units long and pointing north east.

2. You are traveling 30 miles/hour west

30 m.p.h.



Why is this a vector?

Problem 1:

Make up two vector situations complete with drawings.

A vector diagram is simply a drawing of all the vectors in a given situation.

EXAMPLE: Bill and Joe "pull" (exert a force) on a cart in opposite directions.

Construct a vector diagram where Bill pulls harder than Joe.

ANSWER:

(Vector Diagram)

PROBLEM 2:

Construct vector diagrams for the Bill and Joe problem when

a. they both pull with the same force in opposite direction.

b. when Joe pulls harder than Bill

c. Joe and Bill both pull in the same directions.

PROBLEM 3:

Which of the following can be vectors? (Why or why not?)

a. speed

b. distance

c. time

d. mass

e. force

f. acceleration

g. temperature

SEE YOUR INSTRUCTOR TO BE SURE YOU UNDERSTAND VECTORS BEFORE STARTING THE NEXT ACTIVITY!!

LABORATORY EXPERIENCE V

ANALYSIS OF BALANCED FORCES

You are given AAAS booklet Part E,f in this exercise. You are to complete Project A only. Fill out the appropriate work-sheet. Now go on to Project B. Follow directions and balance the lever as indicated. Graph the data. Construct the appropriate vector diagram for the forces involved.

SEE YOUR INSTRUCTOR BEFORE STARTING THE NEXT ACTIVITY!!

SCIENCE—A PROCESS APPROACH / PART E

PREDICTING 5

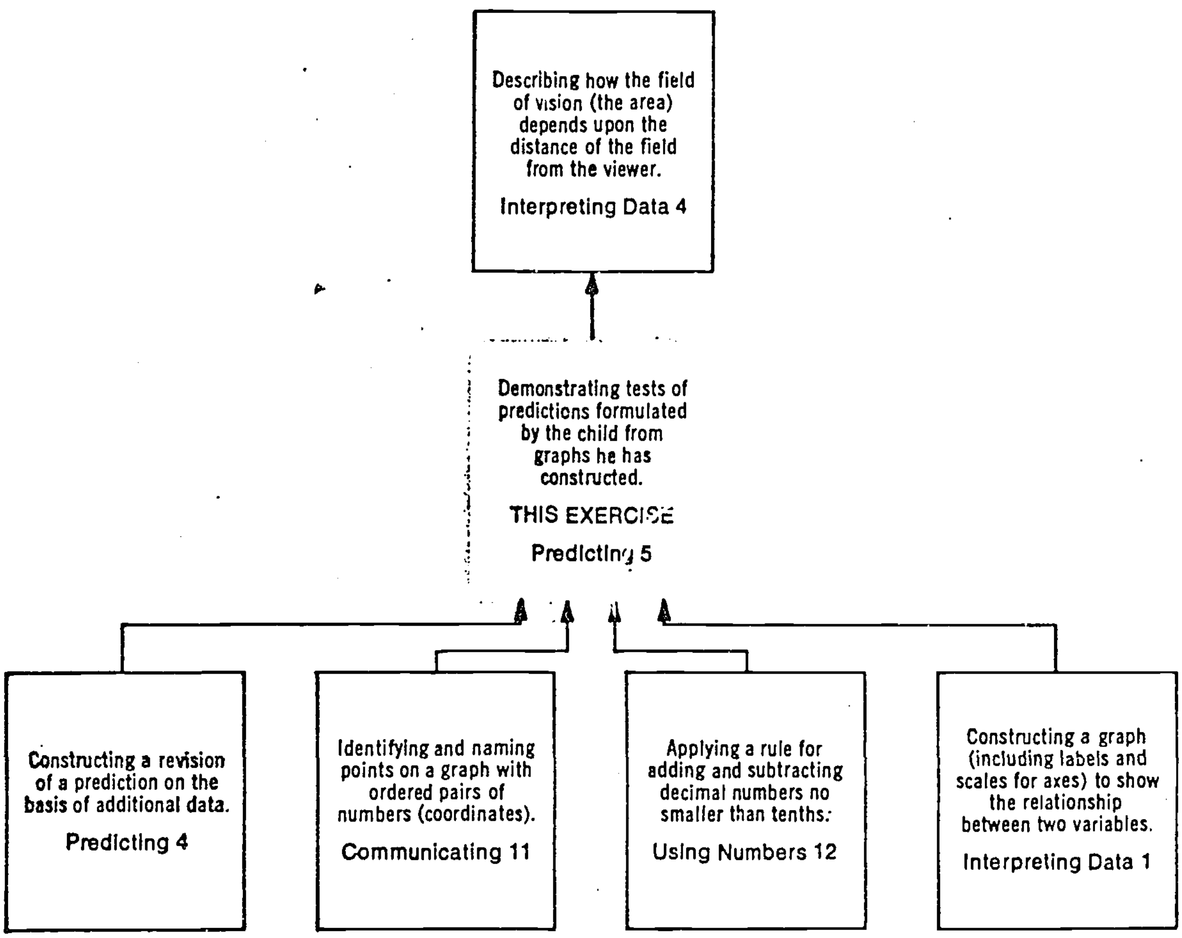
PREDICTION IN VARIOUS PHYSICAL SYSTEMS

OBJECTIVES

At the end of this exercise the child should be able to

1. *NAME* the decimal (tenth) and large-number (to 1000) coordinates of points on a graph with labeled axes.
2. *APPLY A RULE* that the manipulated variable is plotted along the horizontal, or *x*-axis, and the responding variable, along the vertical, or *y*-axis.
3. *CONSTRUCT* a graph, using number pairs that are decimals (tenths) and/or large numbers (to 1000) from data that he collected in investigations with two related variables.
4. *CONSTRUCT* predictions, using a graph.
5. *DEMONSTRATE* tests of his predictions based on graphs.

SEQUENCE



RATIONALE

As the children continue their investigations in science, they will find it increasingly useful to construct graphs to display their data. In an earlier exercise in this Part, *Guinea Pigs in a Maze, Interpreting Data 1, Exercise d*, the children reviewed bar graphs, which they then used to interpret data. They found that they had to use large numbers on one scale.

In this exercise, the children will read and construct graphs that have large coordinates (up to 1000) and decimal coordinates (measured in tenths only), and select scales that are appropriate when one coordinate is changing by small amounts and the other, by large amounts. They will review point and line graphs by plotting data from measurements on simple physical systems. After the children use these graphs to make their predictions, they will return to their projects to test the predictions.

The children will be given the rule that the manipulated variable usually is plotted along the horizontal, or *x*-axis, and the responding variable along the vertical, or *y*-axis. They should be allowed to decide for themselves which scale is appropriate along each axis. Since they may have had a similar experience earlier, you will have to determine how much review and assistance they will need. However, give them some freedom in selecting scales for plotting data even though their first choice may not be satisfactory. By making mistakes, the children should discover that they might have chosen better scales, labeled the axes differently, taken data over a different range of values, or modified their procedure in the investigation.

Although it is not an objective of this exercise, you may wish to distinguish between *discrete* and *continuous* variables. A *discrete* variable is one that can assume only certain values (usually whole numbers), but no others. For example, when the guinea pig went through the maze, the children recorded the maze-times of his first, second, third, and fourth trials; they then plotted these times on a graph with the trial numbers along one axis and the maze-time along the other. The only allowed values for the trial numbers were *1, 2, 3, 4,* and *5*, which are discrete values. A trial numbered *1.5* is meaningless. A *continuous* variable is one that can have any value—one that can be as close to another value as possible, without being the same value. For example, when the temperature of a container of water is measured as it cools, the temperature can assume any value whatsoever in the range between the starting and ending temperatures. The temperature varies continuously.

Other previous exercises in graphing include *Graphing Data, Communicating 7, Exercise g*, Part C; *Using Graphs, Predicting 1, Exercise h*, Part C; *Describing Location, Communicating 11, Exercise j*, Part D; and *The Suffocating Candle, Predicting 4, Exercise m*, Part D. You should refer to these exercises and to the ones on *Communicating* and *Interpreting Data* in the *Commentary for Teachers* before teaching this exercise.

VOCABULARY

pendulum	depend
vibrate	arc
pivot	oscillation

RELATED MATERIALS

Listed below are the materials required to conduct this exercise.

Some items cannot be supplied at all or are not supplied by Xerox in the Standard Kit. These are designated as *NS*. Note, however, that many of these items are supplied in the Comprehensive Kit. These are designated as *COMP*. A separate list of these items is included with the comprehensive materials.

It should be noted that some supplied items are expended in the course of this exercise. These expendable items are designated as *EXP*.

Some of the items used in several exercises and items too large for the Exercise Drawer will be found in the Teacher Drawer and are designated as *TD*.

String (TD, EXP)
Screw eyes, 2
Rubber ball, 1 (NS, COMP)
Sixty-second interval timer, 1 (NS, COMP, TD)
Metersticks, 30 (TD)
Graph (as in Figure 2), 30 copies
Overhead projector, 1 (NS)
Number lines (as in Figure 3), 30 copies
Graph paper, 2-mm squares printed in green ink, 100 sheets (TD, EXP)
Data sheet (as in Figure 4), 30 copies (EXP)
Graph A (as in Figure 5a), 30 copies (EXP)
Graph B (as in Figure 5b), 30 copies (EXP)
Graph C (as in Figure 5c), 30 copies (EXP)
Data sheet (as in Figure 6), 180 copies (EXP)
Equal-arm balances, 3 (TD)
Equal-arm balances, 2 (NS, COMP, TD)
Rods, 5 boxes
Steel bearings, 5 boxes
Containers (use pans from equal-arm balances), 6 (TD)
Containers (use pans from equal-arm balances), 4 (NS, COMP, TD)
Spring Scale–tripod units, 5 (TD)
Pivot mechanisms, 5 (TD)
Springs, 5 (TD)
35-gram washers, 50
50-milliliter test tubes, 5
Red food coloring, 1 bottle (NS, COMP, EXP)
One-hole rubber stoppers, 5
Plastic tubes 20 cm long, 5
Roll of centimeter tape, 1 (TD, EXP)
500-milliliter containers, 5 (found in Exercise "I" drawer)
Celsius thermometers, 4 (TD)
Fahrenheit thermometers, 4 (TD)
Pupil *Group Competency Measure*, 30 copies (EXP)
Individual Competency Measure illustration (as in Figure 17), 3 copies (EXP)
Medicine dropper, 1 (TD)
15-milliliter test tube, 1

INSTRUCTIONAL PROCEDURE

Introduction

Run a long lightweight string through a hook or screw eye in the ceiling or in the top of a door frame and attach it to a screw eye in a rubber ball. This arrangement will provide a single-strand pendulum whose length can be varied.

Start the pendulum swinging gently, with the ball extended almost to the floor. Ask the children to watch it closely and to tell you how they might change the swinging of the pendulum. Here are some ideas that may occur to them: pull the ball farther to one side before you let it swing; pull the ball out only a little way and let it swing; push the ball as it is released; change to a larger (or smaller) ball; or change the length of the string. Be prepared to try as many of these suggestions as possible, particularly the first one.

Pull the ball to one side so that it swings in a wide arc. After the children have observed several swings, stop the ball and let it swing from a position only 10 to 20 centimeters from rest position. They will probably agree that the ball swings "faster" when it swings in a wider arc. Ask them to suggest ways in which they can be more certain that the ball swings "faster" in one trial than in another. Perhaps they could count the number of swings of the pendulum in one minute, which might be different in the two trials. Test this answer by counting swings for one minute, while the ball swings in a wide arc. Start the time period at the moment the ball is released. When it returns to the point of release for the first time, count "One," and so on. Repeat the test for a small arc.

Since the number of swings counted in each test will be almost the same, you may want to repeat the tests to satisfy those who had expected a large difference. The discussion that follows should conclude that although the number of swings counted in the two tests was about the same, the ball traveled a greater distance in the first test than in the second.

The observations show that a clear definition of *faster* and *slower* is needed for describing the motion of the pendulum. The ball moves faster when it is displaced farther from the rest point because it travels a greater distance to complete a swing. However, the number of swings counted per minute is almost the same whether the ball swings in a wide arc or a small one. (The exercise, *Describing the Motion of a Revolving Phonograph Record, Measuring 14, Exercise 1,* Part D, includes a similar problem.)

Later in this exercise, the children may say that the ball swings "faster" when they shorten the length of the pendulum so that the number of swings counted per minute will increase as the pendulum is shortened. To avoid confusion when using the words "faster" and "slower," make it clear whether the reference is to the speed of the ball as it moves through an arc or to the number of swings per minute (the frequency).

Finally, shorten the string to about 30 centimeters to test whether the length of the pendulum might influence its motion. When the pendulum is set in motion, the children should observe that it swings with a greater frequency. Ask, **How much faster does it swing now than it did before? How would the pendulum swing if you changed its length so it is somewhere between the old length and the new one?** The children will probably reason that the motion should be between the fast and the slow rates associated with the short and long lengths. Counting the number of swings the ball makes in one minute at each length and comparing these counts is the class project for *Activity 1.*

Activity 1—Collecting and Graphing Data for a Simple Pendulum

This activity demonstrates the procedure to be followed in *Activity 3* when the children work in small groups.

First, define the problem: **How does the number of swings the pendulum makes in one minute depend on the length of the pendulum?** Suggest that the class take some measurements and record them. Devise a system which will require the children to participate. You might have some children measure time, some measure length, and some count.

The sequence of measurement might be as follows. Measure the length of the pendulum in centimeters from the point of support to the center of the ball. Then start the pendulum swinging gently; and as the second hand on the sixty-second interval timer passes the *60*, let the children chosen to be timers say "Go." At this point, the counters can begin to count the number of complete swings the pendulum makes. They should consider over and back as one swing. When one minute has passed, the timers should say "Stop," and the counters should then stop counting. Trial runs will help the children become accustomed to their duties. Record the data on the chalkboard to stress the number-pair relationship. (See Figure 1.)

Manipulated Variable	Responding Variable
When the length of the pendulum is	the number of swings in one minute is
50 cm	46
70 cm	36
110 cm	29
150 cm	24
180 cm	20
230 cm	18

FIGURE 1

When they have made measurements for several different lengths, ask the children if they can make predictions from the table. Be as specific in your questions as the following example suggests: **If the length of the pendulum was 60 centimeters, how many swings would it make in one minute?** Let the children make their predictions; then have them test them by adjusting the pendulum to the suggested length and measuring the number of swings in one minute. Record the new measurements.

Suggest that they use the new measurements to construct a graph. The instructional technique you use will depend upon the children's previous experience with graphs. If they have had considerable experience, you might give them coordinate paper and tell them to label the axes, choose scales for both axes, and plot the points; however, if they are inexperienced, you may demonstrate the construction of a graph on the chalkboard or by using an overhead projector. In either case, emphasize the following rules, both here and throughout this exercise:

1. The values of the manipulated variable are conventionally plotted on the horizontal axis; the values of the responding variable are plotted on the vertical axis. (In this example, the length of the pendulum is the manipulated variable.)
2. Each axis is labeled with the name of the variable and the unit of measure used.
3. The scale is chosen so that all the numbers to be plotted will fit on the paper. Each of the smallest squares may represent one unit, two units, five units, ten units, any other number of uniis, or any fractional part of a unit such as one-tenth unit.
4. The scales are chosen so that the graph extends over most of the graph paper.
5. The scales need not be the same along both axes.
6. The scales need not start at zero.
7. The number pairs are plotted as a point (or dot) and the point is circled, as shown in Figure 2. (Give each child a copy of this graph to use as a reference.)

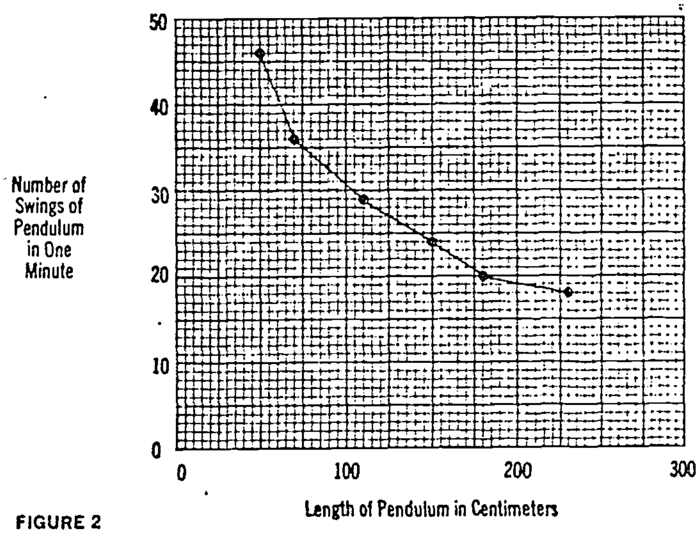


FIGURE 2

To help the children make predictions using the graph, the circles may be joined by either a smooth curve or straight line segments. (A later exercise will explain when to and when not to draw smooth curves.) In Figure 2, the typical data shown in Figure 1 have been plotted and straight line segments have been constructed to connect the points.

Have the children predict from the graph the number of swings that they could count in one minute if the pendulum is 90 centimeters long. Their prediction should be 32 or 33 swings in one minute. However, record all the predictions on the board, whether they are reasonable or not. Now suggest that the children test their predictions by adjusting the length of the pendulum to 90 centimeters and determining the number of swings per minute. Ask, **Did the graph help you to make an accurate prediction?** On the graph, mark the point they found by testing their prediction and tell them to note its location with respect to other points nearby. Tell them to make another prediction from the graph and then repeat the test.

Now adjust the pendulum to a length that has not been measured before. Instead of measuring it, have the children count the number of swings in one minute. Let them predict the length of the pendulum from the number of swings and the graph. Suppose they count 42 swings. From the graph they should predict that the length is between 55 and 60 centimeters. After they have made their predictions have them measure the length of the pendulum and compare the measurement with the prediction.

Activity 2—Using Graphs with Different Scales

Give each child a copy of the three number lines shown in Figure 3, or display them on the chalkboard, or with an opaque or overhead projector. The marks on the lines are identical, but the scales are quite different. Select three points, such as *A*, *B*, and *C*, that have the same position along the number lines, but which represent different numbers.

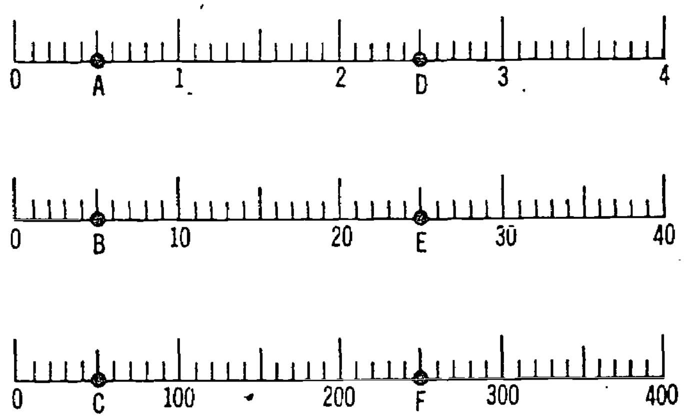
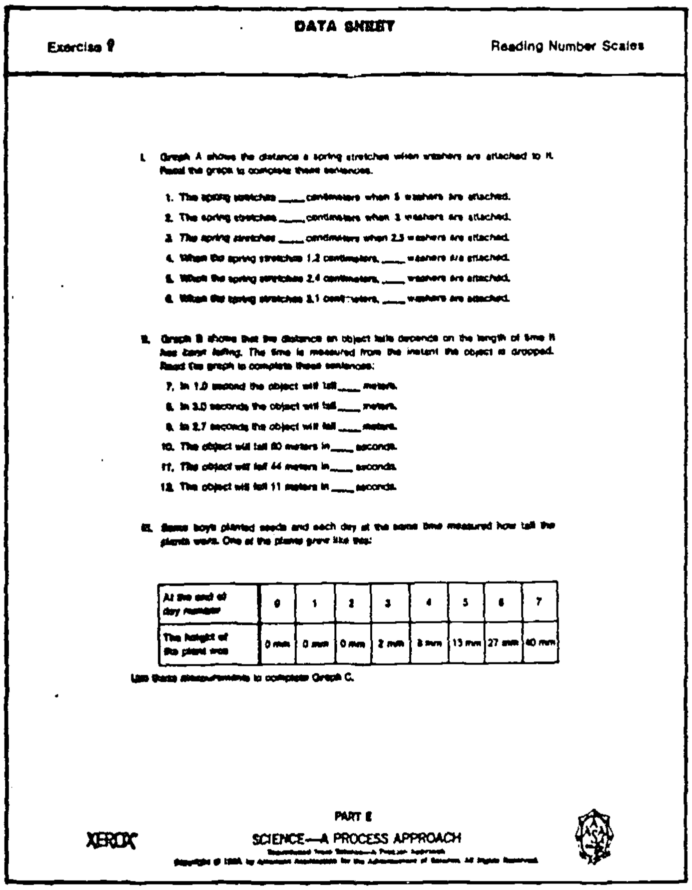


FIGURE 3

Ask the children to name the points labeled *A*, *B*, and *C*. *A* is *0.5*, *B* is *5*, and *C* is *50*. Select other points with similar positions along the number lines and ask the children to name these points: **If the measurement of a variable changed from Point A to Point D, by how much would the variable have changed?** (2.0 units.) **If the measurement of a variable changed from Point B to Point E, by how much would the variable have changed?** (20 units.) From *C* to *F* represents a change of 200 units. Discuss these observations with the children, and point out to them that the scale is important in interpreting the position and change as well as the actual distance along the line. Tell the children that they will be using what they have learned about decimals to read and to make graphs.

Give each child a copy of the data sheet, *Reading Number Scales* (see Figure 4) and also copies of Graphs *A*, *B*, and *C*. (See Figures 5a, 5b, and 5c.) The graphs should be large enough so that the children can read them easily. Tell them that they show how certain responding variables changed when a related variable was manipulated. In Graph *A*, the number of washers attached to a spring is the manipulated variable, and the length of the spring is the responding variable; in Graph *B*, the time of an object's fall is the manipulated variable, and the distance that it falls is the responding variable.



DATA SHEET

Exercise 9 — Reading Number Scales

I. Graph A shows the distance a spring stretches when washers are attached to it. Read the graph to complete these sentences.

1. The spring stretches ____ centimeters when 5 washers are attached.
2. The spring stretches ____ centimeters when 3 washers are attached.
3. The spring stretches ____ centimeters when 2.5 washers are attached.
4. When the spring stretches 1.2 centimeters, ____ washers are attached.
5. When the spring stretches 2.4 centimeters, ____ washers are attached.
6. When the spring stretches 3.1 centimeters, ____ washers are attached.

II. Graph B shows that the distance an object falls depends on the length of time it has been falling. The time is measured from the instant the object is dropped. Read the graph to complete these sentences:

7. In 1.0 second the object will fall ____ meters.
8. In 3.0 seconds the object will fall ____ meters.
9. In 2.7 seconds the object will fall ____ meters.
10. The object will fall 80 meters in ____ seconds.
11. The object will fall 44 meters in ____ seconds.
12. The object will fall 11 meters in ____ seconds.

III. Some boys planted seeds and each day at the same time measured how tall the plants were. One of the plants grew like this:

At the end of day number	0	1	2	3	4	5	6	7
The height of the plant was	0 mm	0 mm	0 mm	2 mm	8 mm	13 mm	27 mm	40 mm

Use these measurements to complete Graph C.

PART E

XEROX — SCIENCE—A PROCESS APPROACH

FIGURE 4

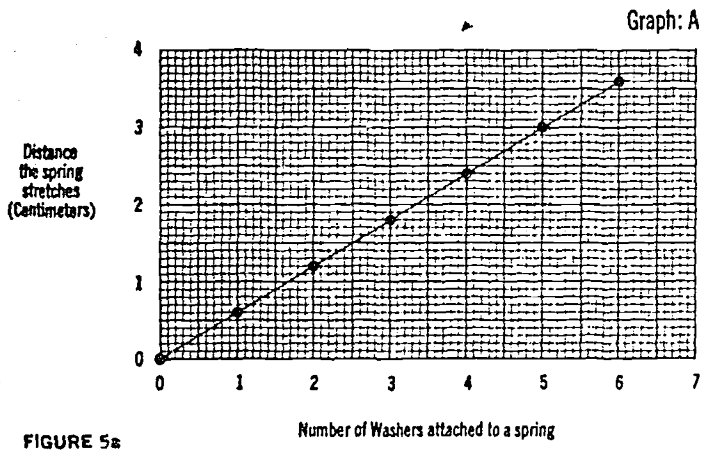


FIGURE 5a

For Graph *C*, each child will construct his own graph, where the manipulated variable is the time at which measurements of the plant's growth are made, and the responding variable is the height of the plant. Point out that time is manipulated in the sense that the moment at which a measurement is made is chosen deliberately—for example, every 24 hours after the seed was planted; or, in the case of the object falling from a high place, every 0.5 second after it was released.

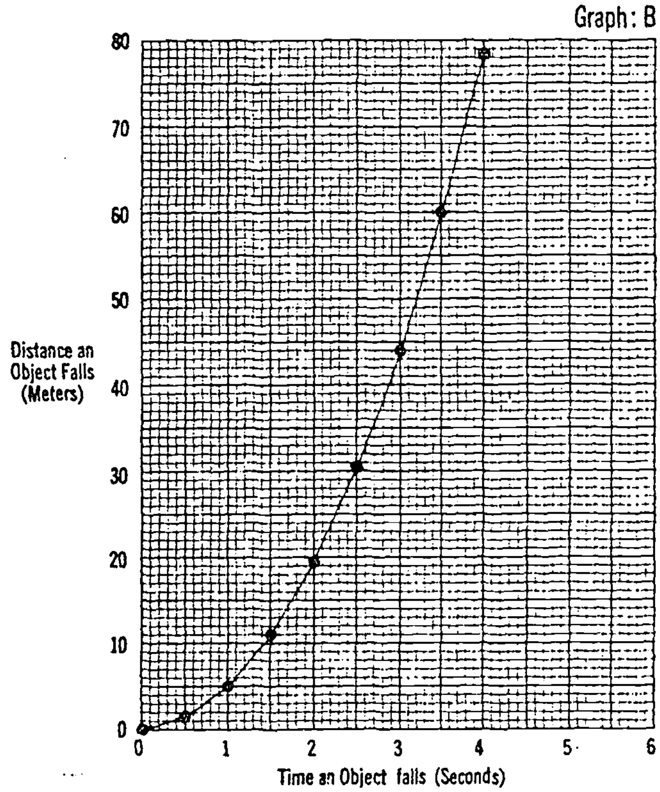


FIGURE 5b

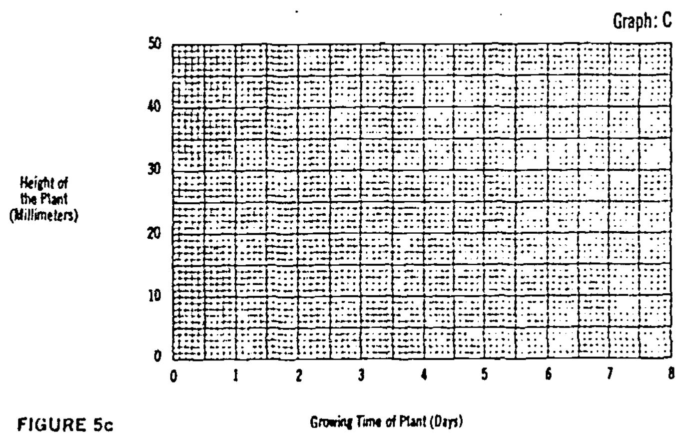


FIGURE 5c

Reading the graphs will provide practice in using coordinates that are large numbers and those that are decimals. Tell the children to notice the scales because they will be making measurements in the next activity and then they will have to choose their own scales. Give the children as much help as they need. When everyone has completed the data sheet, discuss the answers to Questions 1-12 given below, and Graph *C*.

1. (3 centimeters)	7. (5 meters)
2. (1.8 centimeters)	8. (44 meters)
3. (1.5 centimeters)	9. (36 meters)
4. (2)	10. (3.5 seconds)
5. (4)	11. (3.0 seconds)
6. (5.2)	12. (1.5 seconds)

Activity 3—Prediction in Physical Systems

Several projects are suggested in this activity. Select as many as you think will be suitable for the groups to arrange. Have the projects vary in length and difficulty, assigning projects to the children which are commensurate with their abilities. If they remain interested, let the groups exchange projects. Each child should have an opportunity to select scales using decimals and numbers greater than ten.

Divide the children into groups as small as your equipment and facilities will allow. Your experience with *Activity 1* will help you determine how much of the responsibility for planning you can give to the children. Each project requires measurements that can be tabulated as number pairs relating two variables. Have the children devise their own data tables or use those which you provide. (See Figure 6.)

Encourage the children to choose scales for the graphs in which all the data points will be included on the pages, and the graphs will extend over most of the page. If the scales are too small, all the data will be plotted in one small corner of the graph paper or run along close to one of the coordinate axes. If the scales are too large, all of the data cannot be plotted on the page.

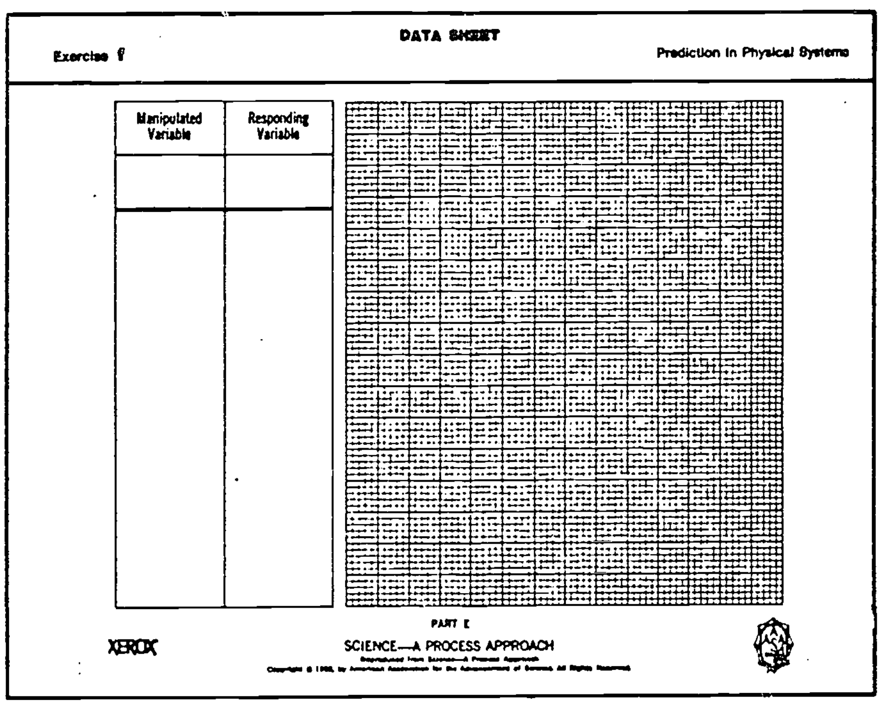


FIGURE 6

Project A—Balancing Steel Bearings and Rods: Give the children an equal-arm balance, a box of steel bearings, and a box of rods. Other objects will work as well, but the weight of the objects in one set should be much less than the weight of the objects in the other set. For example, a rod weighs much more than a steel bearing. Have the children determine the number of steel bearings that will just balance several numbers of rods. The *number* of steel bearings and the corresponding number of rods comprise a number pair. Let the children choose a scale, label the axes, plot the points, and join the points with straight-line segments.

After examining the graph, they should predict how many steel bearings would be required to balance a number of rods they have not used before. Let them test their predictions by actually making the measurements. Have them repeat this activity. Figure 7 shows a typical table of numbers and a graph which may help you. With different rods and different steel bearings, the table and graph should be similar, although the numbers will be different.

Manipulated Variable	Responding Variable
Number of Rods	Number of Steel Bearings
1	10
2	20
4	41
6	62

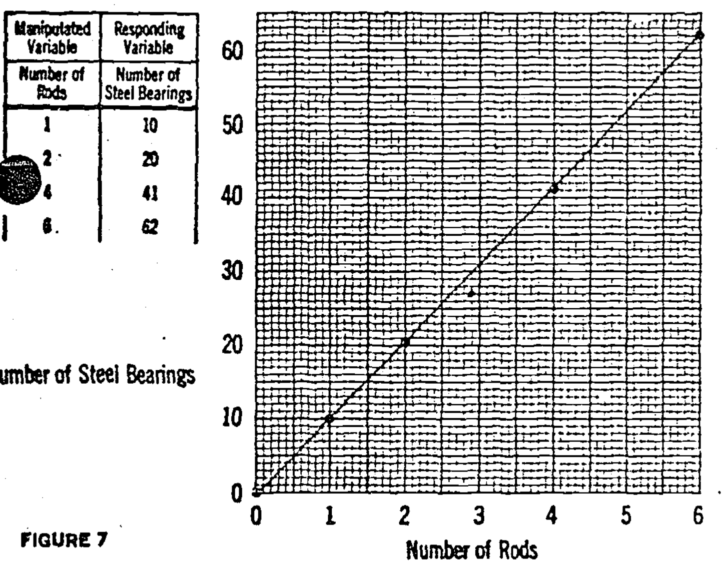


FIGURE 7

Project B—A Balancing Lever: With a tripod provided in the kits, suspend a meterstick at its center so that it is balanced. Hang a pan or container from the meterstick at a distance from the pivot point. This distance will remain constant. On the other side of the pivot, hang a pan or container whose distance from the pivot can be changed, but whose weight will remain constant. (See Figure 8.)

Locate the pan of constant weight at a measured distance from the pivot, and record this distance. Record the number of screws, marbles, or other objects that must be put in the other container (distance constant) to make the device balance. Move the pan of constant weight to a new location and repeat the operation. Record the data in a table, as was shown in Figure 6, with "distance of constant weight from pivot" as the manipulated variable and "number of objects required to balance" as the responding variable.

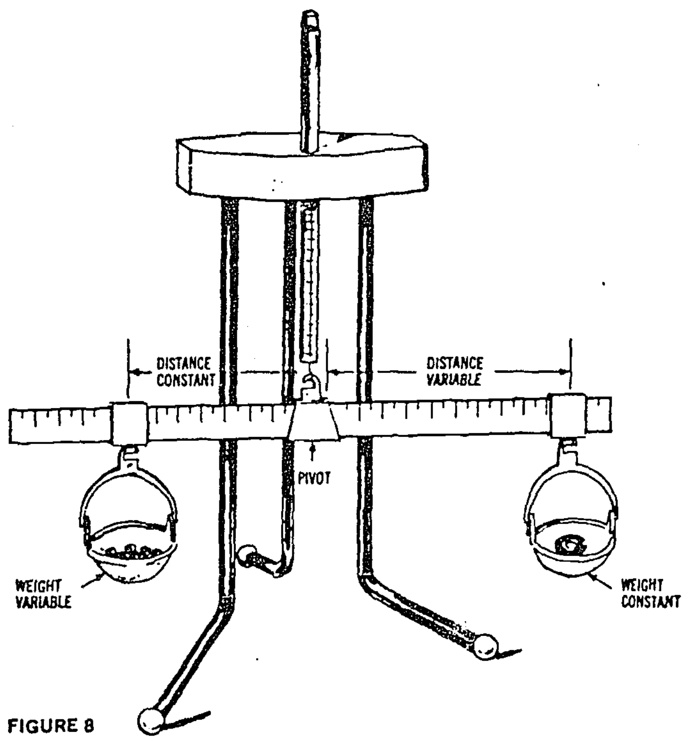


FIGURE 8

Project C—The Stretch of a Spring: In this project, the children will study the relationship between the elongation of a spring, or heavy rubber band (the responding variable), and the number of objects attached to it (the manipulated variable). Attach a spring or rubber band (within a plastic tube) to a support, as shown in Figure 9. Washers, clusters of washers, or other objects having identical weights should be hung from the end of the spring; the elongation or stretch is measured by reading a scale which is taped to the side of the tube, or by measuring the length of the spring with a meterstick or metric ruler. The stiffness of the spring should determine the objects to use. For best results, the length should increase by 2 to 5 centimeters for each object added. The measured elongations and the corresponding number of objects will form a set of number pairs that the children can graph. The children should measure lengths to tenths of a centimeter, and mark off the scale for plotting elongation, with each small division representing one-tenth of a centimeter. This will give them practice in using decimals. Have them record their data in a table like that shown in Figure 6.

After the children have graphed their data, have them predict elongations for combinations of washers they have not already measured and then test their predictions.

Project D—Vibrations of a Spring: In this project, the children will study the relationship between the number of vibrations of a spring in one minute (the responding variable), and the number of objects attached to it (the manipulated variable). Attach a washer to the end of a spring that is supported from a tripod, as shown in Figure 10. Stretch the spring about 5 centimeters by pulling down on the washer. When the washer is released, the system will oscillate for at least one minute. Have the children count the number of vibrations of the spring in one-half minute or one minute. As they repeat their observations with three and then five washers attached to the spring, they should record the data in a table like that in Figure 6 to form number pairs which will be used in a graph. Tell them to make a graph and use it to predict the number of vibrations in the same time period when two, four, or six washers are attached to the spring. Have them test their predictions. Figure 11 shows typical data and a graph. Note that in this case it is both permissible and desirable to start the numbering along the *y*-axis at a number other than zero.

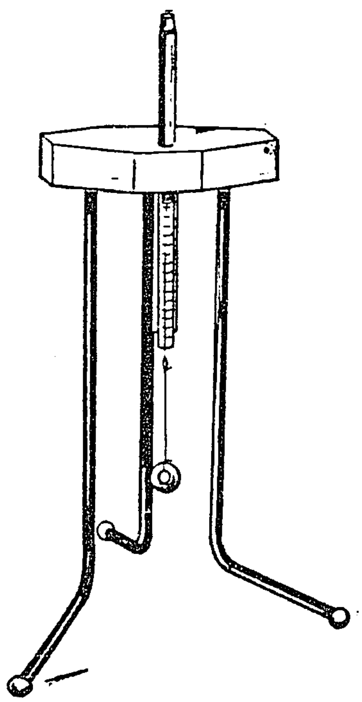


FIGURE 9

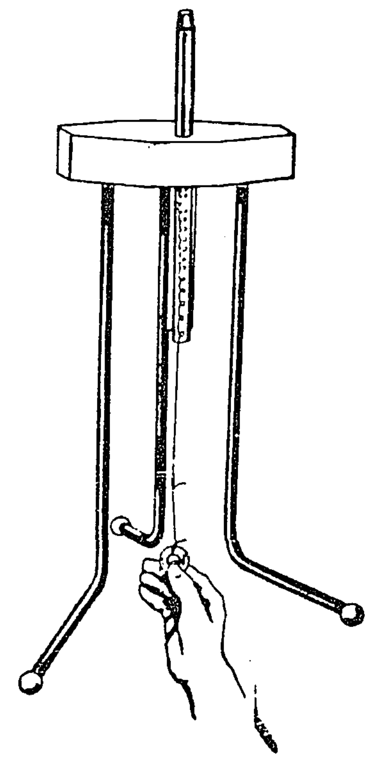


FIGURE 10

You can make an alternative apparatus for this activity by attaching a wooden platform about 15 × 25 centimeters to the end of a screen-door spring with four strong cords. Connect the other end of the spring to a rigid support about 1.5 meters above the floor or table. If you put a brick on the platform, the device will oscillate at the rate of about 90 vibrations per minute. The number of oscillations per minute will decrease as the number of bricks increases. If the spring is very stiff, oscillations may be obtained by fastening two springs together, end to end. If the spring is very weak, suspend the platform from two springs side by side.

Manipulated Variable	Responding Variable
Number of Washers	Number of Vibrations per minute
1	112
2	88
3	68
4	60
5	52

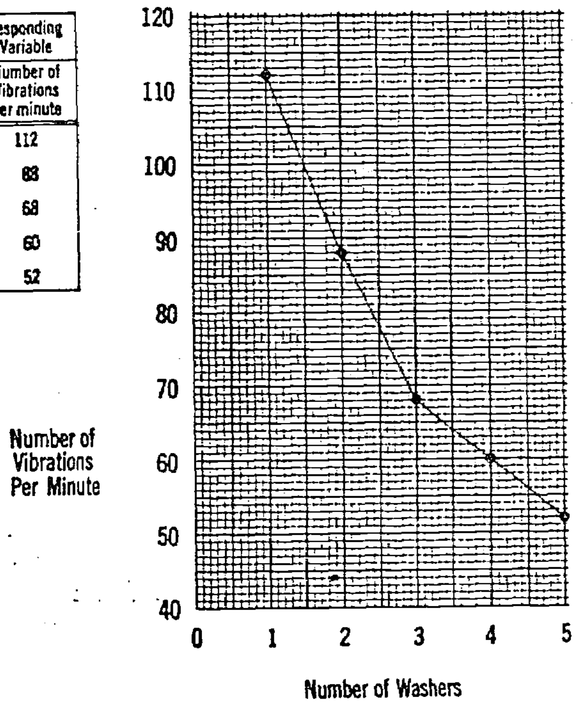


FIGURE 11

Project E—Expansion of Water: In this project, the children will observe the expansion of water as it is heated, and measure how the changes in volume depend on the time that a stoppered container remains in a hot-water bath. Provide a 50-milliliter test tube filled with cold tap water and colored with two or three drops of food coloring. Stopper the test tube with a one-hole stopper in which a 20-centimeter length of plastic tube has been inserted, as shown in Figure 12. Tape an adhesive millimeter scale or a transparent metric ruler to the plastic tube in order to measure the height of the water level. You will also need a 500-milliliter container with water about 30° warmer than

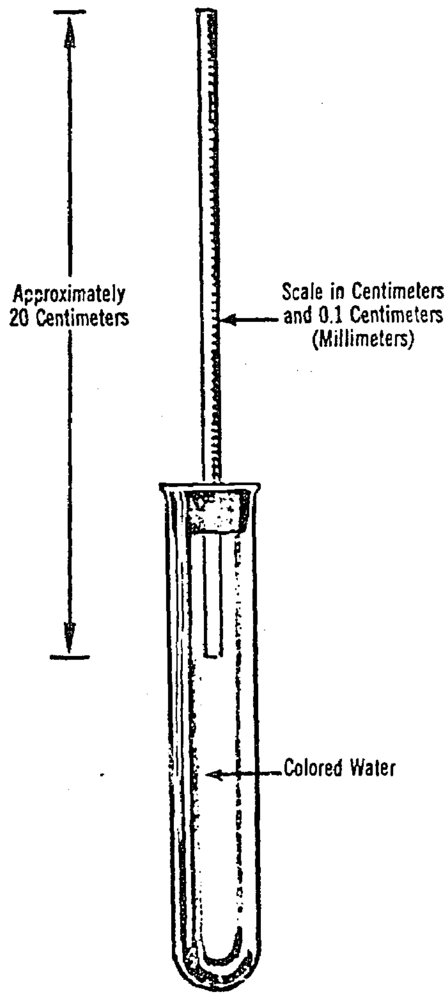


FIGURE 12

room temperature. When the tube is put in the water bath the water level will rise with time. Let the children decide at what intervals they will read the height of the water (probably every 30 seconds or every minute). They should note the height of the water in the tube before the test tube is put in the warm water (the zero-time reading), then insert the test tube in the bath, and start the timing. Have them record the time (the manipulated variable) in seconds or minutes and the height in millimeters or centimeters. Using seconds and millimeters will give the children experience with large numbers; using minutes and centimeters will give them experience with decimals. Have the measurements continue until the water level is no longer changing (about six minutes). Figure 13 shows typical data and a graph. Encourage the children to use scales that do not begin with zero.

Manipulated Variable	Responding Variable
Time (Minutes)	Height (Centimeters)
0.0	2.0
0.5	3.2
1.0	4.2
1.5	5.0
2.0	5.7
2.5	6.2
3.0	6.6
3.5	6.9
4.0	7.2
4.5	7.4
5.0	7.6

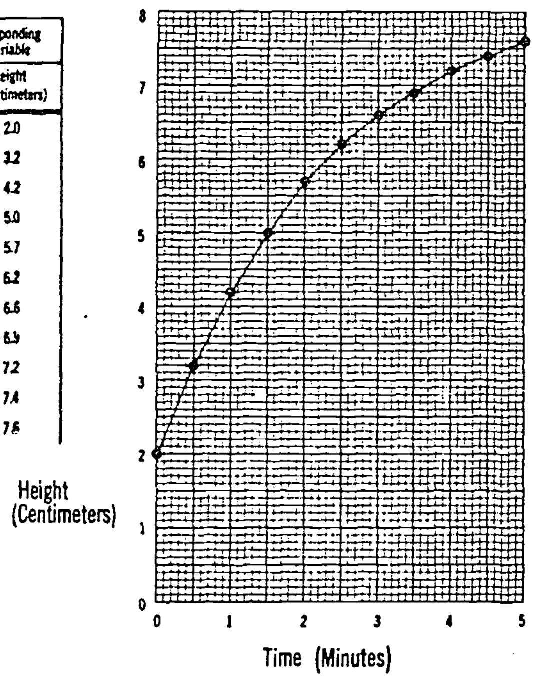


FIGURE 13

At the end of this activity, let the children share their results and experiences. They should be able to make measurements using decimals and numbers larger than ten, construct graphs using number pairs from these measurements, make predictions from the graphs, and then test their predictions.

GENERALIZING EXPERIENCES (Optional)

1. Have the children measure a variety of temperatures from 0°C to 100°C (indoors, outdoors, near a radiator, near a window, and so on), with both Celsius and Fahrenheit thermometers. From the data, let them construct a graph similar to the one shown in Figure 14, and use it to convert temperature readings from one scale to another. Give the children several Fahrenheit or Celsius temperatures and ask them to use the graph to convert the values to the other temperature scale.

   Some children may be interested to extrapolate the line so they can read "below zero" temperatures. Encourage them to do this. They may discover that the two scales come together at −40°.

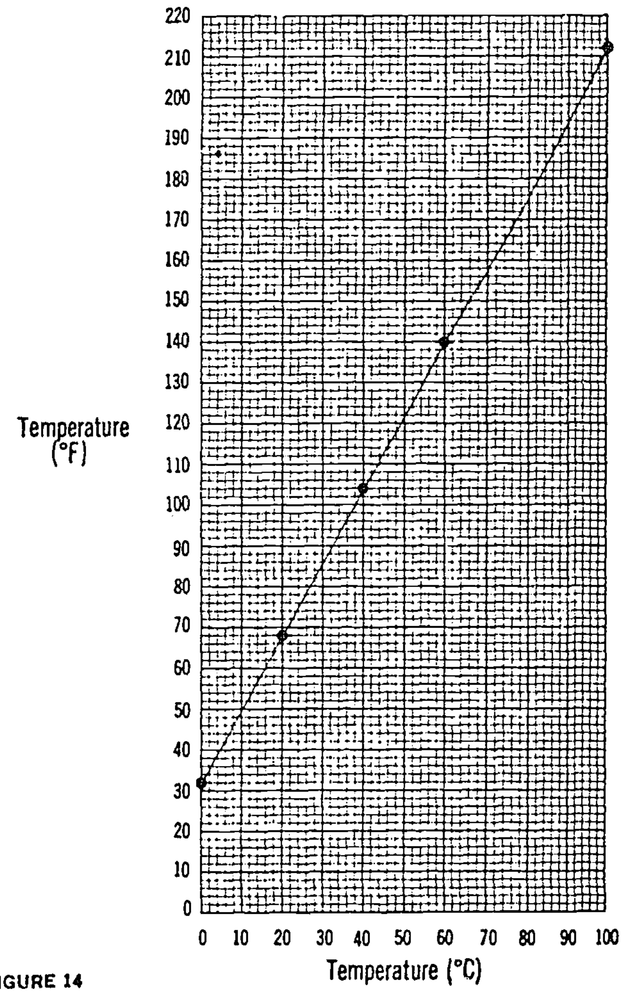


FIGURE 14

2. Show the children the table of data presented in Figure 15 which lists the distances of the planets from the sun and the time in earth years that the planets take to go around the sun once. Explain that the distances are given in *Astronomical Units (A.U.)*. One A.U. is equal to 150,000,000 (150 million) kilometers, or 150,000,000,000 (150 billion) meters, the average distance from the sun to the earth.

   If the children make a graph using the information in the table, it should resemble Figure 16. You can then ask them a number of questions that will help them to read their graphs and to make predictions. Here are a few sample questions:

   1. **Which planet goes around the sun in the shortest time?**
   2. **Which planet goes around the sun in a shorter time, one that is near the sun or one far away from it?**
   3. **If a planet were at a distance of 15 Astronomical Units from the sun, how long would it take to go around the sun once?**
   4. **If you found a planet that went around the sun in a period of 190 years, how far would it be from the sun?**

Planet	Distance from Sun in Astronomical Units	Period in Years
Mercury	0.4	0.2
Venus	0.7	0.6
Earth	1.0	1.0
Mars	1.5	1.9
Jupiter	5.2	12.0
Saturn	9.6	29.0
Uranus	19.2	84.0
Neptune	30.1	165.0
Pluto	39.6	250.0

FIGURE 15

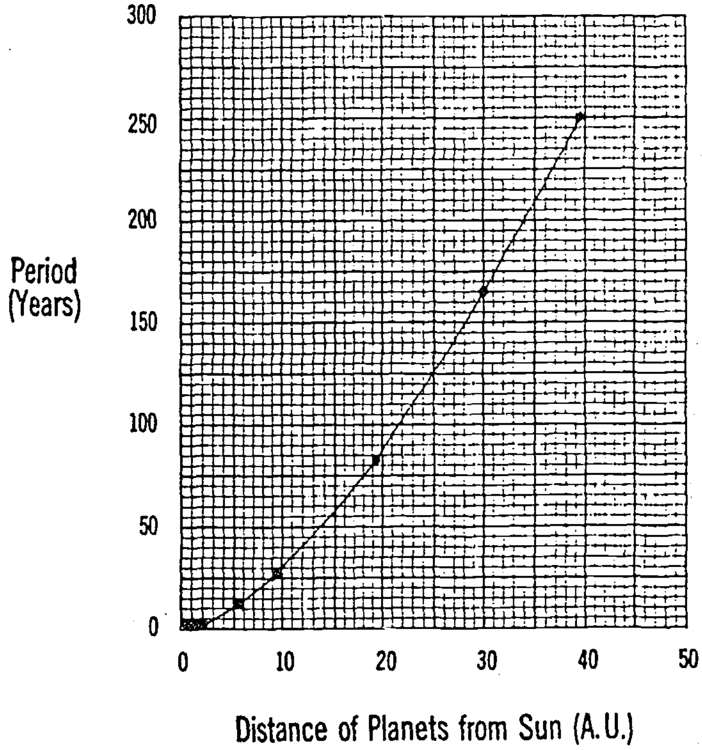


FIGURE 16

GROUP COMPETENCY MEASURE

(Individual score sheets for each pupil are in the Teacher Drawer.)

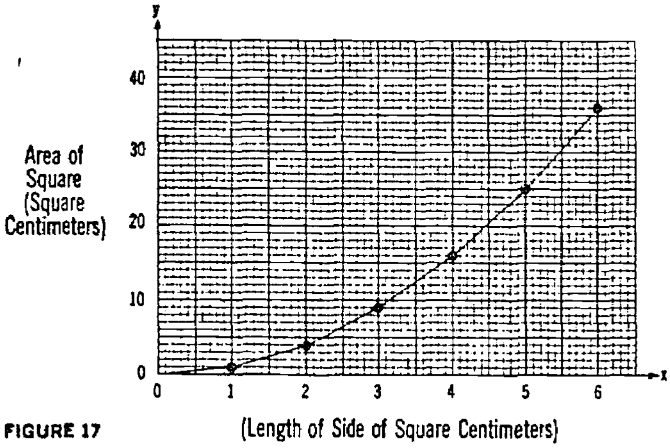


FIGURE 17

TASKS 1-3 (OBJECTIVE 1): This graph (see Figure 17) shows how the area of a square depends on the length of the sides of the square.

1. What is the area of a square whose sides are 5 centimeters? ____________
2. What is the area of a square whose sides are 3.6 centimeters? ____________
3. If a square has an area of 21 square centimeters, what is the length of its sides? ____________

Acceptable Behavior

For Task 1, the child writes "25 sq cm" or "25 square centimeters"; for Task 2, he writes "13 sq cm" or "13 square centimeters"; for Task 3, he writes "4.6 cm" or "4.6 centimeters."

TASKS 4-7 (OBJECTIVES 2, 3): The five pictures below (see Figure 18) show how the level of water rose in a cylinder as twenty more drops were added from a medicine dropper each time. A piece of centimeter tape was attached to the cylinder so that the water level could be measured easily.

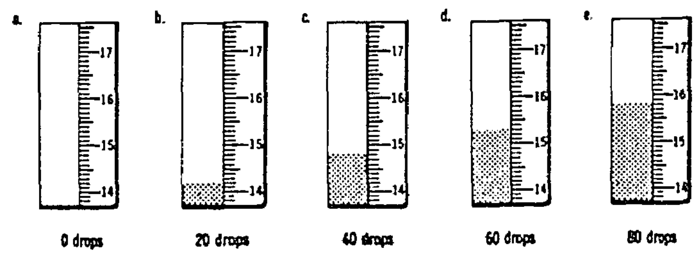


FIGURE 18

Read the height of the water in each cylinder and record the pairs of data in the table below. The zero reading is already tabulated. Choose scales for the height and the number of drops; label the axes on the graph paper grid; and construct a graph from your data.

Manipulated Variable	Responding Variable
Number of Drops	Height of Water (Centimeters)
0	13.7

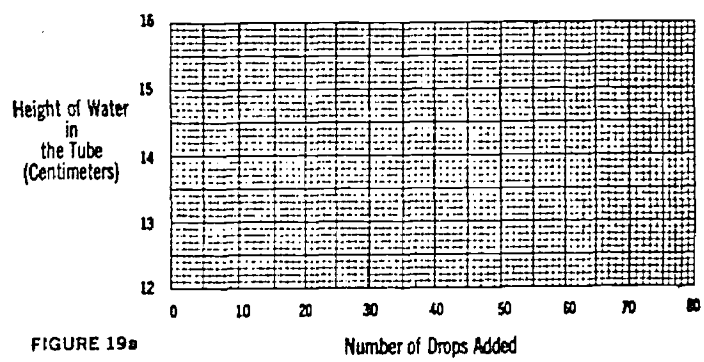


FIGURE 19a

Acceptable Behavior

For Task 4, the child completes the table of data and chooses the horizontal axis (*x*-axis) for plotting the number of drops; for Task 5, he selects a scale for the number of drops that extends from 0 to 100, or so; for Task 6, he selects a scale for the height of the water which permits locating points to the nearest 0.1 centimeter; for Task 7, he correctly locates the points he has recorded in the table and joins the points with straight line segments, or a smooth curve. (The data and graph should look like those shown in Figure 19b.)

Manipulated Variable	Responding Variable
Number of Drops	Height of Water (Centimeters)
0	13.7
20	14.2
40	14.8
60	15.3
80	15.8

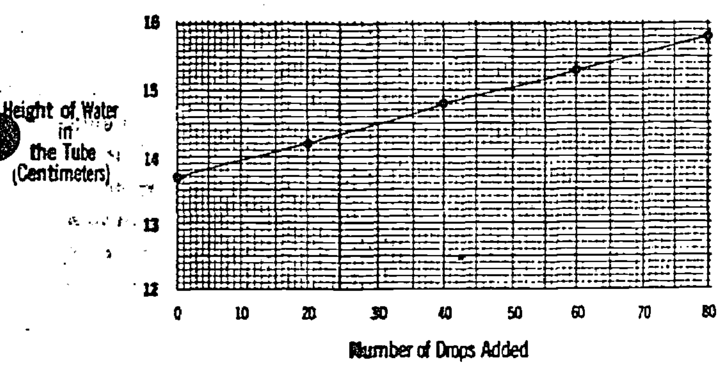


FIGURE 19b

TASKS 8-9 (OBJECTIVES 4, 5): Suppose now that you emptied and dried the cylinder and then put 35 drops of water into it. Use your graph to predict what the level of the water would be. Write your prediction here:

________ cm

Now write in your own words what you would do to test your prediction.

____

____

____

____

Acceptable Behavior

For Task 8, the child makes a prediction consistent with his graph; for Task 9, he writes an account in his own words which includes adding 35 drops to the empty and dry cylinder with the medicine dropper, reading the new level of the water, and comparing the reading with his prediction.

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C.1

INDIVIDUAL COMPETENCY MEASURE

TASKS 1-3 (OBJECTIVE 1): Give the child a copy of the graph that shows how the area of a square is related to the length of the edge of the square. (See Figure 17.) Point to the graph and say, **This graph shows how the area of a square depends on the length of the side of the square. What is the area of a square whose sides are five centimeters?** Give the child time to respond. **What is the area of a square whose sides are three and six-tenths centimeters?** Give the child time to respond. **If a square has an area of twenty-one square centimeters, what is the length of its sides?**

Acceptable Behavior

For Task 1, the child says "25 square centimeters"; for Task 2, he says "13 square centimeters"; for Task 3, he says "4.6 centimeters."

TASKS 4-7 (OBJECTIVES 2-3): Give the child a medicine dropper, a container of water, a 15-milliliter cylinder with a centimeter tape or scale attached, a piece of paper on which a data table is outlined, complete with headings *(manipulated variable: number of drops; responding variable: height of water)*, and a large sheet of graph paper. Say, **When water is added to the cylinder with the medicine dropper, the water level in the tube will rise. Count the number of drops that you add and measure the height of the water. Add about twenty drops at a time. Record your measurements in the table where I have already put the zero-heading for your cylinder so that you can make a graph of the height and the number of drops.** When the child has recorded four number pairs on the table, say, **Choose a scale for the height and the number of drops, label the axes on this graph paper, and construct a graph from your measures.**

Acceptable Behavior

For Task 4, the child chooses the horizontal axis for plotting the number of drops; for Task 5, he selects a scale for the number of drops that extend from 0 to 100, or so; for Task 6, he selects a scale for the height that permits him to locate points to the nearest 0.1 centimeter; for Task 7, he correctly locates the points he has measured and joins these points with straight-line segments or a smooth curve. (The data and graph should look something like those shown in Figure 20.)

Manipulated Variable	Responding Variable
Number of Drops	Height of Water (Centimeters)
0	13.7
20	14.2
40	14.8
60	15.3
80	15.8

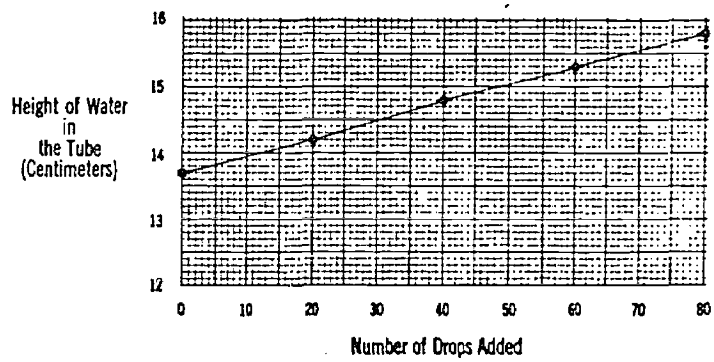


FIGURE 20

TASKS 8-9 (OBJECTIVES 4-5): Empty the tube and dry it. Say, **Suppose that thirty-five drops were added to the test tube. Use the graph you constructed to predict what the height would be.** Record the child's prediction. **Go ahead and test your prediction.**

Acceptable Behavior

For Task 8, the child correctly reads his graph to make a prediction; for Task 9, he adds 35 drops to the test tube, reads the height of the water from the scale, and compares the measurement with his prediction.

Manipulated Variable	Responding Variable

PART E

SCIENCE—A PROCESS APPROACH

Reproduced from Science—A Process Approach

5069

LABORATORY EXPERIENCE VI

SPRING CALIBRATION IN NEWTONS

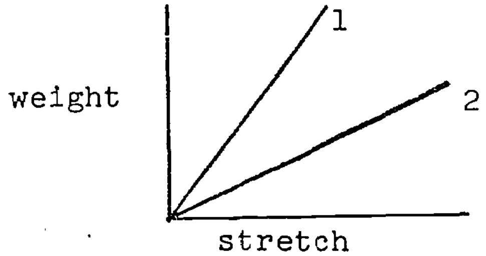
I. You are now given AAAS booklet Part E,s and you will complete activity 2. Make a graph of stretch of the spring versus weight.

QUESTION 1: Does the slope of the graph tell you anything about the "tightness" of the spring?

II. If a different kind of spring is available repeat the experiment and graph the data on the same graph paper.

QUESTION 2: Which spring is "tighter"? How can you tell from the graph?

QUESTION 3: In the graph below which spring is "looser" (easier to stretch)? How do you know?



III. You are now given an unknown weight, place it on your spring.

QUESTION 4: How can you tell how many Newtons the weight is from the graph?

QUESTION 5: Did you interpolate or extrapolate your data?

QUESTION 6: Make a force vector diagram for the spring-weight system.

SCIENCE—A PROCESS APPROACH / PART E

MEASURING 18

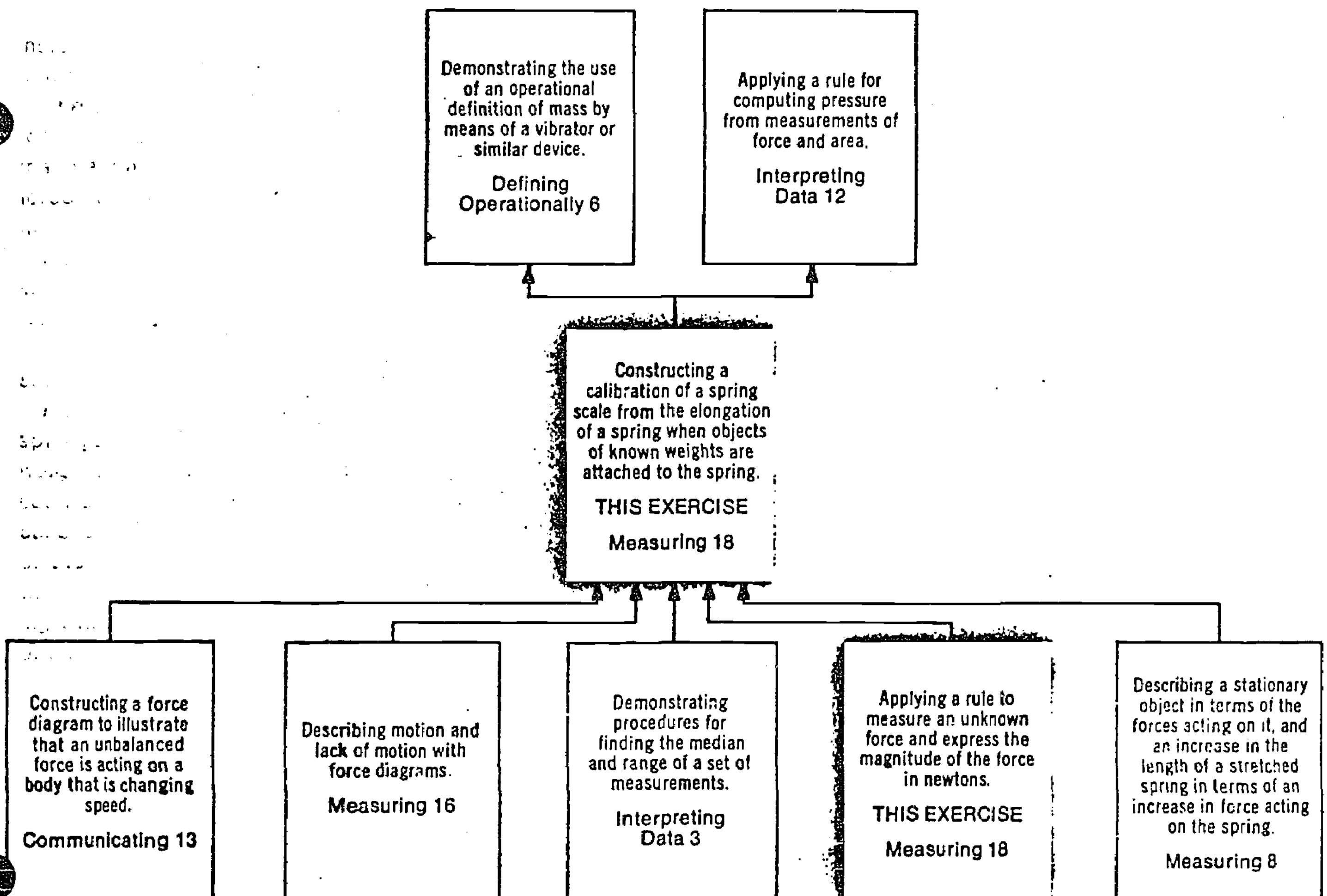
A UNIT OF FORCE

OBJECTIVES

At the end of this exercise the child should be able to

1. *CONSTRUCT* a calibration of a spring scale by measuring the elongation of the spring when objects of known weight are attached to the end of it.
2. *APPLY A RULE* to measure an unknown force, and express the measurement in the standard metric unit of force, the newton.

SEQUENCE



RATIONALE

Until now, the process of measuring forces has been limited to making comparisons with the spring scale or the equal-arm balance. The children have expressed their comparisons by statements such as these: This toy weighs more than that toy; or, this block weighs the same as 17 paper clips. They have discussed forces and represented them by vectors. They have also expressed forces in arbitrary units of measure of the stretch of a spring or a rubber band.

This exercise introduces the standard unit of force in the metric system, the *newton*. This word should cause no more difficulty than the word *meter* did when it was introduced. The newton should be used in the same sense as the pound, the unit of force in the British system. The newton and pound are both units of measure of the same thing, force. However, the size of the two units is different, just as the size of the foot and the size of the meter are different. One pound is equal to about 4.5 newtons. Thus, instead of saying that a brick weighs 6 pounds, you say that it weighs 27 newtons.

The children will measure how far springs stretch when forces of 1, 2, 3, and 4 newtons are applied, and they will make a graph to show how the elongation depends on the force. This graph calibrates the springs. Then they use the graphs to measure unknown forces.

Activity 1 is similar to *Project C, Activity 3,* in *Prediction in Various Physical Systems, Exercise f.* The purpose of *Activity 1* is to establish the need for a standard unit of force. You can omit *Activity 1* if the children can already state why a standard unit is necessary.

Note on the calibration of springs: To calibrate the springs the children will attach standard 1-newton weights. Give these objects to the children, and say that each one weighs 1 newton. They can use these objects to calibrate their springs by recording the length of stretch of the spring and the amount of standard force applied. Each group of children will need four objects, each weighing 1 newton. With weaker springs, you should use weights of less than 1 newton.

VOCABULARY

newton

calibrate

RELATED MATERIALS

Listed below are the materials required to conduct this exercise.

Some items cannot be supplied at all or are not supplied by Xerox in the Standard Kit. These are designated as *NS*. Note, however, that many of these items are supplied in the Comprehensive Kit. These are designated as *COMP*. A separate list of these items is included with the comprehensive materials.

It should be noted that some supplied items are expended in the course of this exercise. These expendable items are designated as *EXP*.

Some of the items used in several exercises and items too large for the Exercise Drawer will be found in the Teacher Drawer and are designated as *TD*.

- Container, 1 (NS)
- Assorted rubber bands, ½ box (NS, COMP)
- Assorted objects weighing between 0.2 and 5 newtons, including two sets of identical objects (NS)
- Graph paper, 2-millimeter squares printed in green ink, 65 sheets (TD, EXP)
- Tripods, 5 (TD)
- Centimeter tape (TD)
- Plastic tubes, 5 (TD)
- Springs with a constant of 1 newton per centimeter, 5 (TD)
- Springs with a constant of 0.2 newton per centimeter, 5 (TD)
- Springs with a constant of 0.05 newton per centimeter, 5 (TD)
- Bolts, 10
- Washers, 10
- Paper clips, 1 box (NS)
- 1-newton weights, 10
- 0.5-newton weights, 5
- 0.2-newton weights, 5
- Metric rulers, 5 (TD)
- 5-gram washers, 50
- 35-gram washers, 50 (found in Exercise "f" drawer)
- Pupil *Group Competency Measure,* 30 copies (EXP)

INSTRUCTIONAL PROCEDURE

Introduction

Display a container with a rubber band attached, and two or three objects of different weights. Ask the children to compare the forces needed to lift them. They should be able to order the objects from heaviest to lightest—that is, from the greatest force to the smallest force. Ask them to describe how much larger one force is than another. Ask them to compare the force necessary to stretch the rubber band 5 centimeters with the force required to stretch the rubber band 10 centimeters. Because they have neither an arbitrary unit nor a standard unit for measuring force, they will have difficulty stating quantitative answers. They may suggest that the force required to stretch the rubber band 10 centimeters is twice as great as the force needed to stretch it 5 centimeters.

This exercise is based on the technique of measuring forces using springs. Remind the children that they have already learned a unit of measure for length, area, volume, and time. In the next activities, they will learn a unit of measure for force.

Activity 1—Measuring Forces Using Arbitrary Units (Optional)

(The purpose of this activity is to demonstrate the need for a standard unit of measure for force. Two different springs are calibrated in terms of arbitrary units by measuring how much they stretch with weights attached. The need for a standard measure is demonstrated when the children try to compare their measurements of the weight of an "unknown" object in terms of arbitrary units. However, you can omit the activity if the children can already describe why a standard unit is necessary.)

Give the children both plain paper and graph paper, and tell them that you would like each of them to make a graph showing the increase in length of a spring as different numbers of objects are attached to the bottom of it. Suggest that the scale for the number of objects attached be on the *x*-axis; and the scale for the increase in length of the spring, on the *y*-axis.

Divide the class into five groups and provide each group with a tripod from which to suspend a spring and the weights. Give some of the groups one kind of spring that they calibrate using a set of identical objects, such as bolts. Give the other groups a different spring that they calibrate using a different set of identical objects, such as washers. The objects can be attached to the springs with bent paper clips.

After the groups have made their graphs of elongations against the number of objects attached, distribute two sets of objects in such a way that identical objects are weighed on the two different springs. Have the children determine the weights of the objects by measuring how far they stretch the springs and then interpolating from the graphs. For each object, one group will express the measurements in terms of the weight of bolts, and the other, in terms of washers. The children should see that the elongations of the two different springs for identical objects are different.

If the groups read their graphs correctly, some will agree, for example, that an object weighs the same as 3.5 washers, and others will state that it weighs the same as 5.2 bolts. Ask, **If you were a scientist or an engineer, how would you communicate to someone else the weight of the object or the size of the force?** (Send a washer and say that the object weighed the same as 3.5 of these, or send the spring and say that it stretched 8.0 centimeters.) Neither of these is convenient.

Review how the standard units of length and volume were agreed upon so that people everywhere would know what was meant when it was stated that a length was so many centimeters or a volume so many milliliters. Tell the children that they will learn to use the standard unit of force in the metric system, the *newton.*

Activity 2—Calibrating Springs to Measure Force in Newtons

Give each group of children a tripod, a spring mounted in a plastic tube with a centimeter scale or tape attached, graph paper, and two standard 1-newton weights. For weaker springs (0.2 and 0.05 newton per centimeter) the "standard" weights should weigh 0.5 and 0.2 newton, respectively. (Refer to *Rationale*.)

Point out that the scale alongside the spring measures the stretch of the spring in centimeters. Tell the children that you want them to *calibrate* the springs attached to the tripods. They need to devise some scheme for using the spring in order to measure forces in newtons. Show them the standard weights. Tell them that the heaviest one weighs 1 newton; and when it is attached to the end of the spring, it will exert a force of 1 newton. The smaller weights weigh 0.5 and 0.2 newton, and when they are attached to the ends of the springs, they will exert forces of 0.5 and 0.2 newton. Let the children proceed when it seems to you that they understand the problem. They may use graph paper if they wish. Help them as necessary.

One way to calibrate a spring is to hang one (see Figure 1), then two, then three, and then four of the 1-newton weights from it and then read from the scale the location of its end. (Have neighboring groups combine their weights, in turn, to accomplish this phase of the calibration.) Next, a graph can be made with the scale reading (in centimeters) plotted along one axis, and the number of newtons of force applied to the end of the spring plotted along the other. Thus, an "unknown" force can be measured by reading the scale when the force is applied to the spring, and then interpolating from the graph.

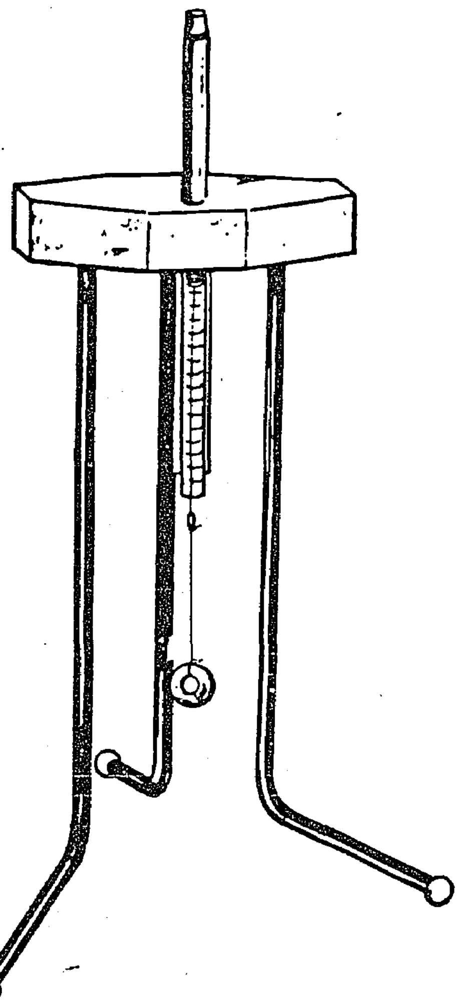


FIGURE 1

Activity 3—Measuring Forces in Newtons

Supply each of the groups with the same equipment they used in *Activity* 2, a centimeter ruler, a labeled rubber band, and a labeled object that can be weighed on the spring scales. The objects should have different weights, and the rubber bands should be of different sizes. Tell the groups that you would like them to do the following:

1. Measure the force of the earth-pull on the object you have given them.
2. Measure the force required to stretch the rubber band 15 centimeters.

Have them record the results of their measurements on the new objects and the rubber bands.

Rotate the objects and the rubber bands among the groups until every group has measured the weight of each object and the force required to stretch each rubber band 15 centimeters. Tabulate these results on the chalkboard, using a table similar to that shown in Figure 2. Then tabulate the forces required to stretch the rubber bands in a similar table. Ask, **How well do the results agree? Can we trace the disagreements to poor technique for calibrating the springs in Activity 1? To careless measurements? To poor record keeping? What is the median of each set of measurements? What is the range?**

	Object A	Object B	Object C	Object D	Object E
Group 1					
Group 2					
Group 3					
Group 4					
Group 5					

FIGURE 2

GENERALIZING EXPERIENCE

Ask the children to lift common objects found in the classroom, and to estimate their weight in newtons. Then let them test their estimations by measuring the force with the springs they have calibrated earlier. In any discussion about forces, stress the idea that weight is a force (a force down), that forces can be exerted in any direction, and that the newton is the standard unit of force in the metric system.

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GROUP COMPETENCY MEASURE

(Individual score sheets for each pupil are in the Teacher Drawer.)

TASKS 1–3 (OBJECTIVE 1): Figure 3 shows four observations made with a spring. Each block weighs 1 newton. From the observations, make a graph on the sheet given you that shows the calibration of the spring.

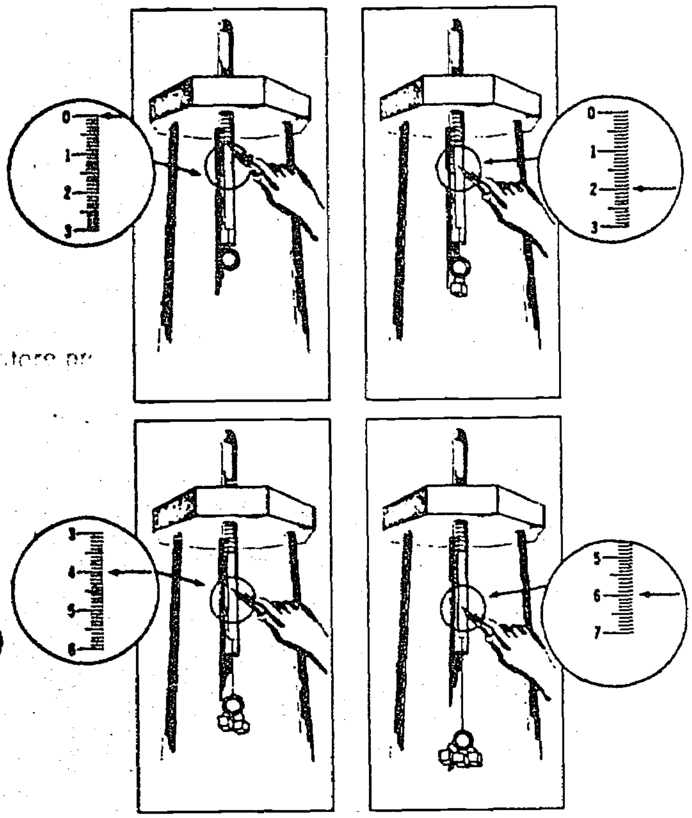


FIGURE 3

Acceptable Behavior

For Task 1, the child marks scales on the two axes and labels them suitably; for Task 2, he correctly plots two of the points *(0,0), (1,2), (2,4),* or *(3,6);* for Task 3, he joins the points with line segments, or draws a straight line through them.

TASK 4 (OBJECTIVE 2): Figure 4 shows a hand stretching the same spring. How much force is the hand using to stretch the spring? Make an arrow on your graph to show this force, and write the amount of it below the arrow.

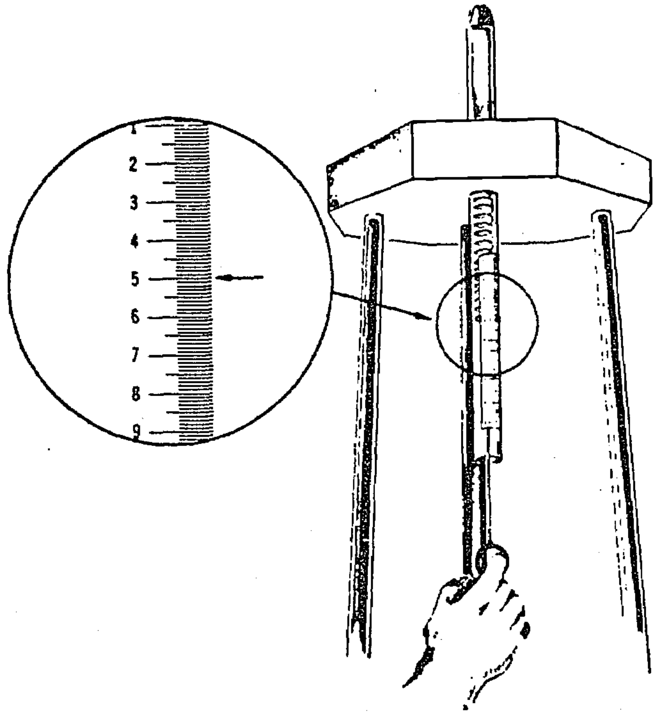


FIGURE 4

Acceptable Behavior

The child locates the point *(2.5, 5)* or the force coordinate *5* with an arrow and writes 2.5n (for newton) beneath the arrow. Allow an error of *0.2* newton.

INDIVIDUAL COMPETENCY MEASURE

(Individual score sheets for each pupil are in the Teacher Drawer.)

TASKS 1–3 (OBJECTIVE 1): Give the child four weights, each weighing 1 newton; a spring that he has not used before, mounted on a tripod; and a pencil and some graph paper. Point to the weights and say, **Each one of these weighs one newton. Use them and the graph paper to calibrate the spring so that you can use the stretch of the spring to measure forces.**

Acceptable Behavior

For Task 1, the child plots one point correctly; for Task 2, he plots two points correctly; and for Task 3, he plots three or more points correctly and joins them with line segments, or draws the "best" straight line through them. If he does not draw an acceptable graph, help him do so before proceeding to Task 4.

TASK 4 (OBJECTIVE 2): Pull on the spring with your hand until it is stretched to some length within the range of calibration. Say, **Measure the force that I am exerting on the spring with my hand and tell me what it is. Draw an arrow on your graph to show me where you are reading the force.**

Acceptable Behavior

The child indicates the correct point on the graph with an arrow, and states the measure of the force in newtons. If he merely gives a value (say *3.5*), prompt him with the question 3.5 what? Allow an error of 0.2 newton.

LABORATORY EXPERIENCE VII

FORCE AND ACCELERATION

INTRODUCTION:

In this experience you will study how an object changes speed or accelerates when a force is exerted on it and how the acceleration varies as the force is increased.

EXPERIMENT

In this experience you will attach a ticker tape to a cart. You will place a rubber band on the cart, stretch it while holding the cart, and then let go of the cart and attempt to keep the rubber band stretched at a constant length while the cart accelerates. A rubber band stretched to a constant length exerts an almost constant force on the cart. You can make a speed versus time graph of the cart from the ticker tape. From looking at the slope of this graph you can tell how the cart accelerated. After you complete a run with one rubber band of force, apply two rubber bands of force and graph the speed versus time data for this run on the same graph as before. One rubber band exerts one unit of force on the cart; two rubber bands stretched to the original length exert double force on the cart.

Summary of directions:

(1) With one rubber band attached to the cart make a run and a speed vs. time graph.

(a) Does the cart accelerate?

(b) How can you tell this?

(2) With two rubber bands stretched to the same length (double the force), make a run and graph the speed versus time data on the same graph.

(a) Which force produces the greatest acceleration?

(b) Increasing the force does what to the acceleration?

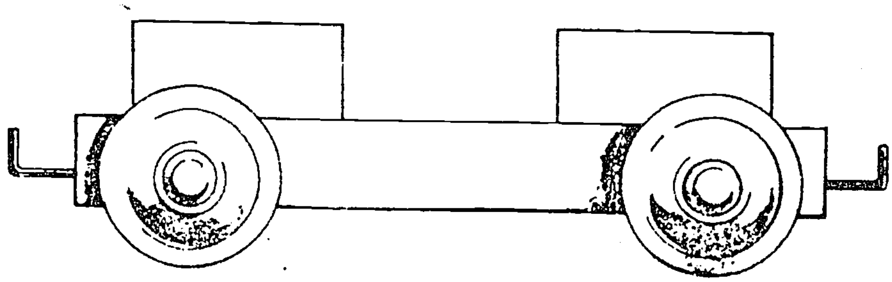
OPTIONAL:

Now make a run accelerating the cart with a string weight pulley set up. Dropping the weight accelerates the cart. Make a speed vs. time graph of the data. Is the acceleration almost constant?

Use these sheets to construct force vector diagrams for each case.

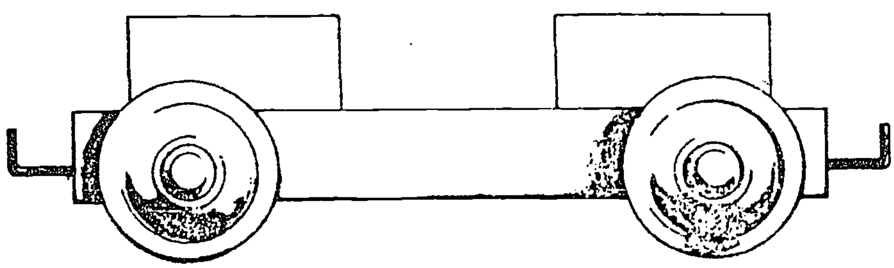
1. Balanced Force Unbalanced Force

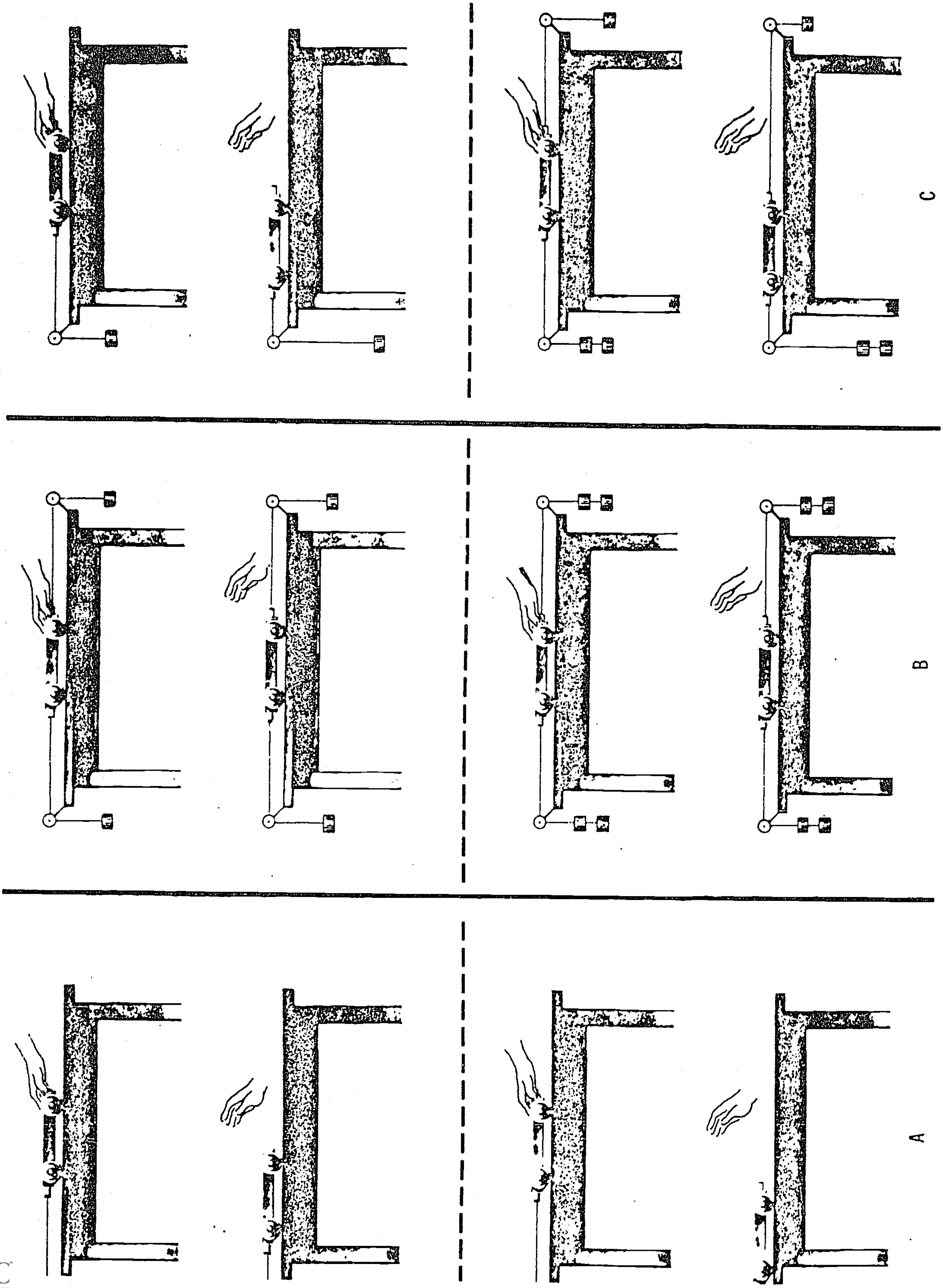
2.



3. Balanced Force Unbalanced Force

4.

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B
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LABORATORY EXERCISE IX

VOLUME OF SOLIDS

In this exercise you are given several objects of different shapes, - a calibrated beaker, a 100 ml cylinder, a one liter graduated cylinder and a 10 ml graduated cylinder.

(1) How can you measure the volume of these solids?

(2) What is the volume of each solid?

NOTE: 1 cubic centimeter (cm^3) = 1 ml