Name: ________________________ Partner(s): ________________________

Investigation #1 ________________________

VARIABLES, MEASUREMENTS AND SCIENTIFIC METHODOLOGY

In this introductory session, you will explore the concept of *variables* and their *values* as well as the basic processes and reasoning in performing a controlled scientific study. By analyzing patterns, you will determine "the rules of the game" and determine what relationship (if any) exists between two variables as you work through a series of short investigations. The data that you collect will then be represented visually by generating a graph for each investigation.

For these investigations, you will identify and measure variables, record data, generate graphs, analyze patterns, make predictions based on those patterns, and then test your predictions. In doing so, you will essentially be doing what professional scientists do (except without the formation of committees or funding applications!)

Note: The vast majority of the laboratory sessions that follow will involve concepts and procedures developed in this session.

Part I-A
Variables and Values
Background

Depending on profession, the term *variable* can have different meanings. For example, in mathematics, a variable often represents an unknown quantity that is to be found. According to Webster's dictionary, a *variable* is "a quantity that can take on one of a set of values." This is generally the definition used in science, although in science, a variable does not have to be a *quantity*—it can also be an attribute or a *quality*.

As an example, an attribute that can be used to describe something may be the "sound" it makes. So sound, in this example, is a variable. What are some *values* of sound? You could say, "dull," "pure," "soft," "blaring," etc. These values describe a quality of sound rather than a quantity of sound. Variables that are described in this way are referred to *qualitative variables*. We could also be more specific about the quality of sound. Perhaps we are interested in the "pitch" of the sound. Qualitatively, the variable "pitch" may be "high" or "low." Maybe we are interested in the "loudness" of the sound. Loudness too, may be qualitatively described as "high" or "low," or "soft" or "loud."

On the other hand, variables that are described by some numerical quantity are referred to as *quantitative variables*. Again, using "pitch" and "loudness" as examples, we note that pitch (also known as <u>frequency</u>) can be numerically described by a particular number of units (called <u>Hertz</u>). Similarly, the loudness (also known as <u>intensity level</u>) can be numerically described by a particular number of units (called <u>decibels</u>).

Depending on the types of measurements you are performing, the variables in your experiments may be qualitative or quantitative in a similar way as described in the examples above.

Identifying Variables and Values

Your group will need the following materials/equipment for this part:

- A set of assorted objects

Procedure

1. With your partner(s), spread the objects in front of you and sort the objects according to some variable of your choice.
2. In Table 1 below, list that variable and identify whether that variable is qualitative (Qlt.), quantitative (Qnt.), or both by checking the appropriate column(s). Then list some representative values of that variable. Be sure that the values you list are consistent with whether the variable is qualitative or quantitative. See the three examples provided in the table.
3. Choose another variable repeat the above procedure. Continue to fill in the table with as many variables as you can. (Don't worry if you don't know the "official" name of a particular attribute—make up an appropriate name if necessary.

Note: For *Sample Values*, do NOT list the items themselves—just list representative values of the variable that you are choosing.

Table 1

Variable	Qlt.	Qnt.	Sample Values
Material	✓		Wood, Metal, Plastic…
Number of Sides		✓	3, 4, 5…
Length	✓	✓	Long, Short (for Qualitative) # inches or # centimeters (for Quantitative)

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** ________

Part I-B
Tables and Graphs
Background

There are several ways in which relationships between quantities can be expressed. Among these are words, equations, tables and graphs.

As an example, consider Newton's 2nd law of motion (which you will study in a future investigation). In words, Newton's 2nd law can be stated: *The net force acting on a body of constant mass is equal to the mass of the body times the acceleration of the body*.

In equation form, the equivalent statement is, $F_{net} = ma$. Equations are generally the most concise way to express relationships between quantities.

Tables list representative values of variables. Most often, tables are used when the relationship between the variables is not yet known. Thus, tables are used to record experimental data. For example, the table in Fig. 1 shows some values of net force acting on a given mass and the resulting acceleration of the mass.

Measurements on a 2.0 kg mass	
Net Force (N)	**Acceleration (m/s^2)**
0	0
2.0	1.0
4.0	2.0
8.0	4.0

Fig. 1

It is seen that changing the size of the net force affects the acceleration of the given mass. What would happen if the mass used was different, say 4.0 kg, or perhaps 1.0 kg? You could then repeat the measurements with those other masses and tabulate those results as well.

Graphs, on the other hand, provide a visual representation of the relationship between variables. By looking at a graph, one can immediately see the general relationship (if any) between variables. Does increasing one variable cause an increase, a decrease, or no change at all in the other variable? Is the graph a straight line or is it curved? Again, this information can be immediately determined from the graph. When the relationship is unknown, the graph can be used to determine a mathematical expression between quantitative variables. Continuing with the Newton's 2nd law example, the data from Fig. 1 is represented on the line graph shown in Fig. 2.

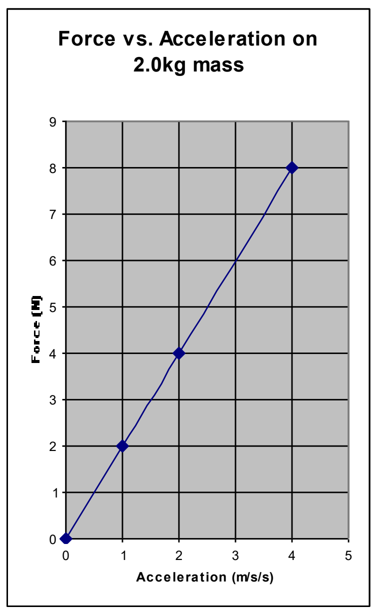

Fig. 2

Question: Look again at the force/acceleration data in Fig. 1 and Fig. 2. According to the information provided, what net force would be required to give the 2.0 kg mass an acceleration of 3.0 m/s^2?

F = _________ N

Question: What acceleration would the 2.0 kg mass have if a net force of 3.0 N were applied to it?

a = _________ m/s^2

When performing an experiment, you are essentially trying to determine the relationship between two variables. That is, you are trying to determine how changing one variable affects another variable. The variable that you are choosing to change is called the *independent variable* because you generally have the "freedom" to manipulate or choose the values of that variable. The response of the other variable is what you are seeking. This responding variable is called the *dependent variable* because it "depends" on the values of the independent variable.

In the example above, the force and the acceleration are the independent and dependent variables. Which variable is the independent variable often depends on which variable is easier to set to the desired values. In this case, it doesn't matter so much. We can choose the acceleration to be the independent variable and the force to be the dependent variable or vice versa. When plotting the graph, however, it is generally customary to place the independent variable on the horizontal axis and the dependent variable on the vertical axis. (There are exceptions: the variable "time" is usually placed on the horizontal axis regardless of whether it is the independent or dependent variable, but not always.)

Since the dependent variable that you are studying may depend on other factors besides the independent variable that you are investigating, it is important to identify (as best you can) what those other factors may be and then "control" them. That is, keep them the same throughout the experiment. These variables are called *controlled variables*.

Question: Why is it necessary to control variables in an experiment?

Question: In the Newton's 2nd law example described Fig. 1 and Fig. 2, what variable is the *controlled variable* (CV)? (That is, what remains unchanged in each measurement?)

CV =

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** ________

After collecting the data and recording it in a table, you are ready to create a graph. Note however, different types of graphs can be generated depending on the type of variables involved and whether the correlation between them is strong or weak.

Bar graphs are used in general classification measurements in which objects are sampled and sorted according to some qualitative variable (such as color, shape, etc.) In these cases, the number of objects having a particular value of the qualitative variable is plotted according to the different values of the qualitative variable under study. For example, the graph shown in Fig. 3 shows a classification of a set of 20 objects that were sorted according to material. The two variables involved here are "material" and "number of objects".

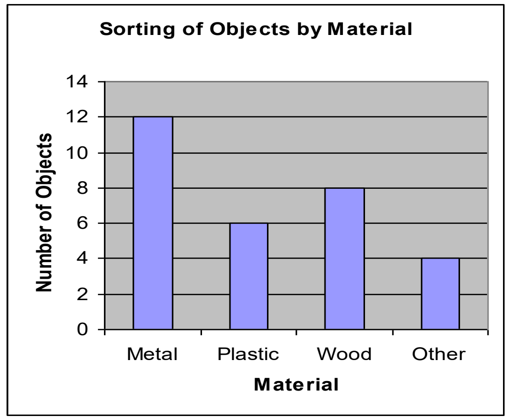

Fig. 3

Question: Look again at the bar graph in Fig. 3. Which variable is the independent variable (IV) and which is the dependent variable (DV)?

IV =

DV =

Note that the order in which the values of the qualitative variable are listed does not matter since there is no number associated with them. That is why it makes no sense to "connect the points" among the data. (A "line plot" is not appropriate for the Fig. 3 data.)

When looking at the relationship between <u>quantitative</u> variables, different types of graphs such as *scatter plots* and *line plots* are used. In particular, scatter plots are used when the correlation between the variables of interest is weak and line plots are used when the correlation between variables of interest is strong. The graph shown in Fig. 4 is an example of a scatter plot. The "Force vs. Acceleration" graph shown in Fig. 2 is an example of a line plot. For a line plot, a *smooth trend* is fitted through the data. The shape of a "line plot" graph does not have to be a straight line. (Even if the trend is curved, the graph is still called a "line plot.")

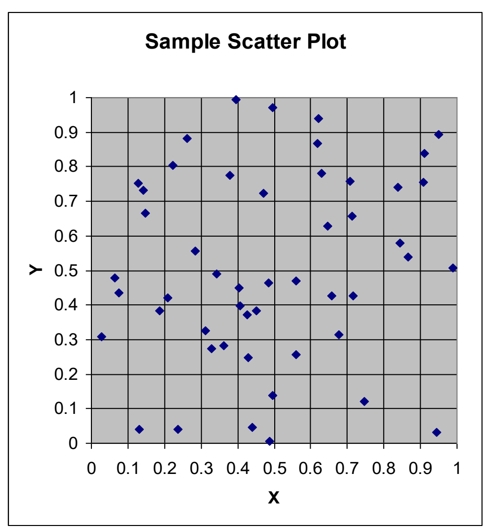

Fig. 4

Part II
The "Rules of the Game"

In this part and the next, you will perform a series of short investigations that will model the essential procedures that scientists generally follow in their professional work. These activities will also allow you to generate each of the graphs described in **Part I-B** as you perform a research study, a classification activity, and study both strongly and weakly correlated variables in a controlled scientific investigation. You will then be asked to answer questions about your data in the **Homework Questions**.

The purpose of this activity is to introduce some basic scientific processes employed by professional scientists as they try to understand a particular phenomenon. In order to develop a theory about a particular phenomenon, the scientist needs to decide on what major questions they need to answer.

Your group will need the following materials/equipment for this part:

- Playing board and playing pieces
- Recorded history of an actual game

Your goal is to develop a "theory" (that is, determine the rules) of the game. In trying to determine the rules of your game, your group will also need to decide on a set of related research questions. For example, you might ask: "Where do the pieces start?" "How do the pieces move?"

Afterward, your instructor will lead a "research conference" where the different research groups come together to explicitly identify major research questions, share proposed hypotheses, discuss evidence, and defend proposals. During the "conference," additional questions may arise as counterarguments are also presented.

Question: In addition to the two research questions (RQ's) listed above, come up with at least three more research questions (for a total of five) that your group will address in the development of your "theory" for this game. Be sure that you reach consensus within your research group.

RQ 1:

RQ 2:

RQ 3:

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** _______

Procedure

1. With the playing board and playing pieces, follow the recorded history of the sample game. You may need to make some assumptions at first.
2. Develop a coherent "theory" of the game. That is, formulate hypotheses based on evidence from the history of the players' moves. It is assumed that the game is being played by two honest players that each know the rules and are trying to win, although the two players are not necessarily experts at this game.

Question: In the space below, write down the answers to your research questions as you discover as well as the supporting evidence in the table below. If for some reason, the sample game history does not provide an answer to one or more of your questions, be sure to record why this is the case in the evidence column.

RQ	Answer	Evidence
How do pieces start?		
How do pieces move?		
1		
2		
3		

Question: In the space below, write down at least two additional rules of the game that you discovered beyond what your original research questions addressed.

4)

5)

Questions: Were there any disagreements within your own research group as your group developed its theory? If so, how were they resolved?

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** ________

At this point your instructor will lead the research conference with the entire class.

Questions: Did other research groups come up with any rules that your group did not? If so, what were they? Do you agree with these additional rules?

Questions: Were there any disagreements among different research groups during the conference? If so, how were they resolved?

Questions: Are there still any unresolved issues regarding the rules of the game? If so, how might these be resolved?

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** _______

Controlled Scientific Investigations
Part III-A
Classification

In this exercise, you will determine the "concentration of colors" in a sampling of an assortment of multicolored objects. The procedure followed here is very typical of how a sampling of a collection of objects can be sorted and analyzed.

Your group will need the following materials/equipment for this part:

- 1 opaque container:
- 1 lid with hole and stopper
- An assortment of multicolored objects

Procedure

1. Choose one of the labeled containers. Be sure to record which container you are using in this investigation in Table 2 below.
2. With the stopper and lid sealing the container, shake the container to thoroughly mix the contents.
3. Remove the stopper and pour out 10 objects.
4. Record the number of each color that appears as the first trial of the data table.
5. Return the 10 objects back into the container.
6. Repeat Steps 2-5 four more times and record the data for the remaining trials.
7. Calculate the overall average percentage of colors for your container and complete Table 2.

Table 2

	Container # _____					
Trial #	# Color A: ___________	# Color B: ___________	# Color C: ___________	% A	% B	% C
1						
2						
3						
4						
5						
	Total # of Color A from all trials	Total # of Color B from all trials	Total # of Color C from all trials	Aver. % A	Aver. % B	Aver. % C

Questions: If you had only performed one trial, how would you rate your confidence (1-10, with 1 = no confidence, 10 = absolutely sure) in your predicted estimate of the true color percentages? Why this rating?

Questions: After performing five trials, how would you rate your confidence? Why?

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** ________

Controlled Scientific Investigations
Part III-B
Examining the Behavior of a Simple Pendulum

You have now gained some experience in distinguishing among different types of variables (qualitative vs. quantitative) and their values, as well as the types of graphs that are appropriate for the data that you collect. Now, you will apply these concepts as you perform a controlled scientific study. In particular, you will explore the behavior of a "simple" pendulum. Your pendulum will consist of a mass connected to a string that is free to pivot about some fixed point.

Now you will construct a "standard" pendulum that will be the basis for future measurements.

Your group will need the following materials/equipment for this part:

- 1 meterstick
- 1 stopwatch
- 1 set of hanger masses
- 1 pivot apparatus (table clamp, rod & pendulum mount & protractor)
- String, paperclips & scissors

Procedure

1. With your partner(s), construct a simple pendulum using the material and equipment provided. Your standard pendulum should consist of a 50 gram mass hanging from a paper clip tied to the string as shown in Fig. 6. The string should be attached to the center pin of the pivot apparatus so that your pendulum is 50 cm *from the pivot to the center of the hanging mass*. Your pendulum should hang freely and the string should coincide with the 90° position of the protractor. If not, you may need to adjust the protractor.
2. When completed, your pendulum should be able to swing without hitting anything.

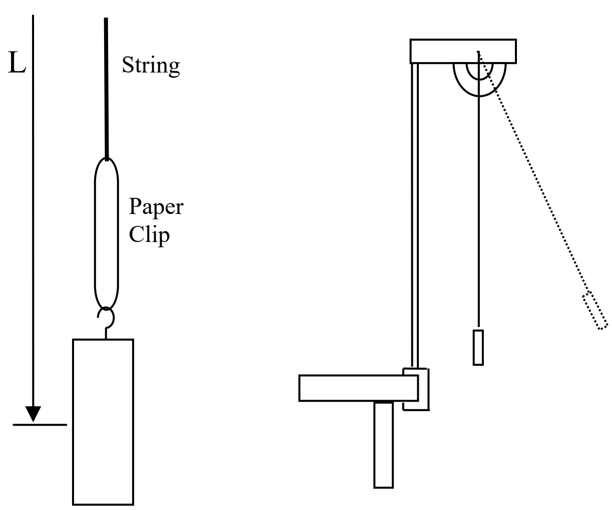

Fig. 6: The basic pendulum set-up.

Note: Since this investigation will be performed as a group, you will need to get your pendulum constructed in a timely fashion so that the entire class is not held up.

3. To determine the time for your pendulum to make 10 swings, the class as a group, will pull the pendulum back 30° off the vertical position and use the stopwatch to record the time.
4. Wait for the cue from your instructor. This measurement is to be done as a class group in order to compare results.

Question: Is there any other information that is needed before starting? If so, what?

Questions: If you want to measure the time for one oscillation, which method will give the more accurate result: starting stopwatch at the beginning of a swing and stopping after one swing, or counting the time for ten swings and then dividing that time by ten? Why?

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5. At this point, every group should have their pendulum along with the starting parameters. On your instructor's mark, measure and record the time that it took for your standard pendulum to complete 10 full swings:

   Trial 1: For your pendulum, the time for 10 swings = _____ s.

Question: Did everyone get a similar result? If not, what might be some reasons as to why?

6. After a brief discussion, your instructor will have you perform a second trial with your "standardized" pendulum. Again, wait for the cue from your instructor.

   Trial 2: For your pendulum, the time for 10 swings = _____ s.

Question: How did everyone's results compare after this second trial?

You will now carry out a series of *controlled experiments* by testing some of the variables that you predicted might affect the time the pendulum takes to perform one *oscillation* ("over-and-back" swing). While there may be many variables suggested, you will focus on the three that are the easiest to manipulate: starting angle, mass, and length.

Angle Variation

The first experiment that you will perform is how *starting angle* affects the *time period* for one oscillation of the pendulum. Since you are essentially free to choose the starting angles to be whatever you wish, the starting angle will be the independent variable for this experiment. Since you do not yet know how the period will respond to changes in the starting angle, the period is therefore the dependent variable.

Question: Note that the total number of swings will be kept the same for each trial. That is, the "number of swings" is a *controlled variable*. List the other two major variables will you control (keep the same) during the angle variation. (Hint: See Table 4.)

Record your data in Table 4 below. (After the laboratory session, graph the results on the graph paper or using plotting software as part of your homework.)

Table 4

Pendulum length: __________ cm	Hanging mass: ____________ g	
Start Angle from vertical (°)	Time for 10 oscillations (s)	Time for 1 oscillation (s)
10		
20		
30		
40		
50		
60		

Questions: Did changing the starting angle affect the period of the oscillation by a significant amount (say 10% or more)? Is there a clear pattern? If so, qualitatively describe the pattern.

Mass Variation

In this second experiment, you will examine how the hanging mass affects the period of the oscillation. The mass is now the independent variable since you can again choose any value of mass to use in this test. We still want to know how the period of the oscillation is affected by changing the mass. Thus, the period of the oscillation is still the dependent variable.

Question: As before, the number of swings is a controlled variable. What other variables will you now control? List them below. (Hint: See Table 5.)

Note: You may need to adjust the length of the string slightly so that the distances between the pivot and middle of the hanging masses are held constant.

Question: What feature of the different masses may make it necessary for you to make the small length adjustments described above?

Record your data in Table 5 below. (After the laboratory session, graph the results on the graph paper or using plotting software as part of your homework.)

Table 5

Pendulum length: __________ cm	Start angle: _________ °	
Mass (g)	Time for 10 oscillations (s)	Time for 1 oscillation (s)
50		
100		
200		
500		

Questions: Did changing the hanging mass affect the period of the oscillation by a significant amount (say 10% or more)? Is there a clear pattern? If so, qualitatively describe the pattern.

Length Variation

In this last experiment, you will investigate how changing the length of the pendulum affects the period of the oscillation. To save time, each group will perform one or two measurements involving different lengths and then record their data on the whiteboard for all groups to access.

Question: What are the independent and the dependent variables in this case?

Question: What major variables will you now control (that is, keep fixed)? List them and their values below.

Record your data in Table 6 on the next page. (After the laboratory session, graph the results on the graph paper or using plotting software as part of your homework.)

Questions: Did changing the length affect the period of the oscillation? Is there a clear pattern? If so, qualitatively describe the pattern.

Table 6

Start angle: _________ °		Hanging mass: ____________ g
Pendulum Length (cm)	Time for 10 oscillations (s)	Time for 1 oscillation (s)
15		
20		
25		
30		
35		
40		
45		
55		
65		
75		
85		
100		
115		
140		
165		

Questions: For the three experiments (angle, mass, and length variation) involving the pendulum, is your data qualitative or quantitative? What type of graphs should you construct for each of these three measurements? (Select the correct responses.)

Data is: ______ qualitative. ______ quantitative.

Graphs should be: ______ bar graphs. ______ line plots.

Checkout: Consult with your instructor before exiting the lab. **Instructor's OK:** ______