LAB 1A – The Scientific Method

Overview

In this laboratory you will first watch a brief video on the importance of laboratory safety, organization and cleanliness. You will then focus on principles relating to the scientific method and the presentation of experimental data after which you will perform an experiment applying these principles. In the second part of this laboratory you will make a variety of measurements in metric units, and practice converting units within the metric system.

Part 1: THE SCIENTIFIC METHOD

The field of science is based on observation and measurement. If a scientist cannot observe and measure something that can be described and repeated by others, then it is not considered to be objective and scientific.

In general, the scientific method is a process composed of several steps:

1. **observation** – a certain pattern or phenomenon of interest is observed which leads to a question such as “What could explain this observation?”
2. **hypothesis** – an educated guess is formulated to explain what might be happening
3. **experiment** – an experiment or study is carefully designed to test the hypothesis, and the resulting data are presented in an appropriate form
4. **conclusion** – the data is concluded to “support” or “not support” the hypothesis

To illustrate the scientific method, let’s consider the following observation:

_A scientist observes that Compound X appears to increase plant growth, which leads to the question: “Does Compound X really increase plant growth?”_

**Hypotheses**

The next step in applying the scientific method to a question such as the one above would be to formulate a hypothesis. For a hypothesis to be a good hypothesis it should be a statement of prediction that:

- a) uses objective, clearly defined terms
- b) can be tested experimentally
A reasonable hypothesis regarding the observation on the previous page would be:

*Increasing amounts of compound X correlate with increased plant height.*

In this case there is nothing vague or subjective in the terminology of the hypothesis, and it can easily be tested experimentally, so it’s a good hypothesis. Keep in mind that a good hypothesis is not necessarily correct. If a hypothesis is clear and testable and experimentation disproves it, valuable information has been gained nonetheless. For example, if testing the hypothesis “supplement Y is safe for human consumption”, it would be very valuable to know if experimental data does not support this hypothesis.

**Exercise A – Good vs bad hypotheses**

Indicate whether or not you think each hypothesis listed on your worksheet is “good” or “bad”.

**Experimentation**

_Experiments_ are designed to test hypotheses. A simple test of the hypothesis on the previous page would be to plant the seeds of identical pea plants in pots containing the same type of soil, being sure that each pot is exposed to the same temperature, pH, amount of sunlight, water, etc, and measure their height after a 5 week period. The only difference between these plants will be amounts of Compound X given to the plants each day, which are as follows:

<table>
<thead>
<tr>
<th>Pea Plant</th>
<th>Compound X per Day (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
</tr>
</tbody>
</table>

In testing the effects of Compound X on pea plant growth, it is common sense that you should devise an experiment in which multiple pea plants are grown under identical conditions except for 1 difference or **variable**, the amount of Compound X given to each plant. In this way any differences in plant height should be due to the only condition that varies among the plants, the amount of Compound X.

When you design an experiment or a study such as this, it is important to consider all of its components. Even though we design the experiment to contain only 1 variable component, we need to consider all other components including the outcome of the experiment and any
control experiments that are done. Thus, when designing an experiment you need to account for the following:

**independent variable**
the treatment or condition that VARIES among the groups

**dependent variable**
the MEASUREMENTS or outcomes recorded at the end of the experiment

**standardized variables**
all other factors or conditions in the experiment that must be kept the same (e.g., type of soil, amount of water, amount of sunlight) so their influence on the dependent variable remains constant (i.e., we want to measure the effect of the independent variable only)

**experimental groups/treatments**
the subjects (e.g., plants) that receive the different treatments

**control group/treatment**
the subjects that receive NO treatment, i.e., the independent variable is eliminated (set to “zero”) or set to a background or default level

*(NOTE: control treatments for independent variables such as temperature and pH that cannot be eliminated are generally at a “background” level such as room temperature or pH = 7)*

**Repetition** is also important for an experimental result to be convincing. There needs to be a sufficient number of subjects and repetitions of the experiment. For example, to make this experiment more convincing multiple plants would be tested at each level of the independent variable and it would be repeated multiple times.

**Data Collection & Presentation**

Upon completion of an experiment, the results need to be collected or measured, and presented in an appropriate format. For our sample experiment, after 5 weeks the height of the pea plants is measured and the following data are collected:

<table>
<thead>
<tr>
<th>Pea Plant</th>
<th>Compound X per Day (grams)</th>
<th>Height of Plant (centimeters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>4.0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>9.9</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>13.2</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>15.1</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>16.8</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>17.0</td>
</tr>
</tbody>
</table>
Now that you have the raw data for the experiment, it is important to present it in a form that is easy to interpret. Frequently this will be in the form of a table, chart or graph. The data above are presented in a table, however the overall results will be easier to interpret if presented in a graph.

There are many ways to present data graphically, but the two most common types of graphs are line graphs and bar graphs. When graphing data in this way, it is customary to place the independent variable on the X-axis (horizontal) and the dependent variable on the Y-axis (vertical). The independent variable in this experiment is the “amount of Compound X added” and the dependent variable is the height of pea plants after 5 weeks. Below are the Compound X data presented in a line graph on the left and a bar graph on the right:

Which type of graph is best for this data? It depends on the nature of the independent variable on the X-axis. If the independent variable is continuous (i.e., there are values for the independent variable that fall between those actually tested), then a line graph would be appropriate. This would be the case if the independent variable covered a range of values for time, temperature, distance, weight, or volume for example. In our example, the “grams of Compound X” is clearly a continuous variable for which there are values in between those tested, therefore a line graph is appropriate. By drawing a line or curve through the points, you can clearly estimate what the “in between” values are likely to be, something you cannot do as easily with a bar graph.

If the independent variable is discontinuous (i.e., there are no values between those tested), then a bar graph would be appropriate. If you wanted to graph the average height of students at each table in the lab (tables 1 through 6), the independent variable is the “specific table”. Even though we label each table with a number, there are no “in between” values, there are only tables 1, 2, 3, 4, 5 and 6, that’s it! So in this case a bar graph would be appropriate.
When you’re ready to create a graph, you need to determine the range of values for each axis and to scale and label each axis properly. Notice that the range of values on the axes of these graphs are just a little bit larger than the range of values for each variable. As a result there is little wasted space and the graph is well spread out and easy to interpret. It is also essential that the units (e.g., grams or centimeters) for each axis be clearly indicated, and that each interval on the scale represents the same quantity. By scaling each axis regularly and evenly, each value plotted on the graph will be accurately represented in relation to the other values.

**Conclusions**

Once the data from an experiment are collected and presented, a conclusion is made with regard to the original hypothesis. Based on the graph on the previous page it is clear that all of the plants that received Compound X grew taller than the control plant which received no Compound X. In fact, there is a general trend that increasing amounts of Compound X cause the pea plant to grow taller (except for plants 5 and 6 which are very close).

These data clearly support the hypothesis, but they by no means prove it. In reality, you can never prove a hypothesis with absolute certainty, you can only accumulate experimental data that support it. However if you consistently produce experimental data that do not support a hypothesis, you should discard it and come up with a new hypothesis to test.

**Exercise B – Effect of distance on making baskets**

In this exercise, you will design an experiment to determine the effect of distance on the accuracy of shooting paper balls into a beaker (and also determine which person in your group is the best shot!). Each student will attempt to throw small paper balls into a large beaker at 3 different distances in addition to the control (which should be 0 cm, i.e., a slam dunk!). You will measure each distance using the metric system and determine how many attempts are made out of 10 total attempts at each distance.

1. State your hypothesis and identify your independent and dependent variables.

2. Place the large beaker on your lab table at each test distance and record how many attempts out of 10 you make.

3. Graph the data for each member of your group on a single graph (use different curves for each person) and answer the corresponding questions on your worksheet.

4. Conclude whether or not the data support your hypothesis and answer any other associated questions on your worksheet.
Applying the Scientific Method to the Game “Purble Shop”

“Purble Shop” is a game found on PCs that run the Windows 7 operating system. In the game you try to guess the colors of various parts of a “Purble” (a funny looking animated creature) in as few guesses as possible. So what does this have to do with scientific inquiry? Like science, the game is about finding out something which is unknown. The approach to discovering “the unknown” in this game has much in common with the scientific method: asking questions, formulating hypotheses, testing hypotheses, and reaching conclusions based on test results. Let’s review the game to see just how scientific this game really is…

Each Purble has 5 features or parts (hat, eyes, nose, mouth, clothes), each of which can be one of 5 colors (red, purple, yellow, blue or green). The computer will generate a hidden Purble with unknown colors for all 5 features. Your job is to make a series of guesses as to the color of each Purble feature until you arrive at the correct color combination. After each guess you will be informed how many of your color choices are “right color, right feature” or “right color, wrong feature”. There are a limited number of guesses, so just guessing randomly will get you nowhere. However if you take a scientific approach you can usually guess the colors of the mystery Purble in 6 attempts or less.

The key to success is to make guesses (hypotheses and experiments) that when tested will yield information (results and conclusions) that is useful in formulating your next guess, which you test and so on... Science generally works this way. The answer to a scientific question usually requires multiple experiments, with the conclusions of one experiment providing information used to formulate the next hypothesis and experiment. In this way, just as in Purble Shop, the ultimate answer being sought is arrived at step by step.
Your instructor will go through a sample game for the class to give you an idea how to approach the process, after which you can practice with your group for a bit. There are many different ways to approach this game, several of which your instructor will show you. Ideally you will devise your own approach with the help of your lab mates. Whatever approach you take, it should be logical and it should minimize the number of guesses required to identify the Purble.

When your group is ready, you will play an “official” game while recording each step and the corresponding thought process on your worksheet. As you play, keep in mind the following suggestions:

1) Limit your first few guesses to one or two colors each. This will give you reliable information you can use for subsequent guesses. If you use all 5 colors for your first guess it will be difficult to come to any conclusions you can rely on for the next guess.

2) Each guess should be consistent with the results of all previous guesses. Take your time to carefully examine each guess (hypothesis) you are considering and make sure it meets the criteria you have already deduced from previous guesses. If it doesn’t, discard that hypothesis, it is not worth testing, and come up with another that is consistent with the criteria you have deduced.

Keep in mind that this doesn’t have to be perfect, you will likely find mistakes in your logic and conclusions along the way. The important thing is to learn the process and to realize how similar this is to the scientific method. But don’t forget that identifying the Purble in as few guesses as possible is the goal. In the real world, science costs money, and scientists who answer important questions with the least amount of experimentation (i.e., time and money) have the most success.

**Exercise C – A game of “Purble Shop”**

Once you and members of your group are familiar with the game of “Purble Shop”, play a single game as a group, recording each guess (hypothesis and experiment), result and conclusion on your worksheet as the game progresses until you identify the Purble.
LABORATORY 1A WORKSHEET

Name ________________________

Section_______________________

Exercise A – Good vs bad hypotheses

Circle good or bad for each hypothesis, and underline any terms that make a hypothesis bad:

1. Students who own laptops have higher GPAs. Good or Bad
2. Murders occur more often during a full moon. Good or Bad
3. Cats are happier when you pet them. Good or Bad
4. Orangutans are smarter than gorillas. Good or Bad
5. Sea level will be higher in 100 years than it is today. Good or Bad

Exercise B – Paper basketball experiment

State your hypothesis:

In the table below, record the number of shots made at each distance (out of 10) for each person:

<table>
<thead>
<tr>
<th>Name</th>
<th>0 cm</th>
<th>____ cm</th>
<th>____ cm</th>
<th>____ cm</th>
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Graph the data for each member of your group below (use a different curve for each person):
What is your control in this experiment?

What is the independent variable?

What is the dependent variable?

State your conclusion addressing whether or not the data support your original hypothesis:

**Exercise C – A game of “Purble Shop”**

*Fill in the table below as your group progresses through a game of Purble Shop. Indicate the number of “right color, right feature” and “right color, wrong feature” for each guess, and write down any conclusions your group makes based on all results up to that point:*

<table>
<thead>
<tr>
<th>guess #</th>
<th>right color, right feature</th>
<th>right color, wrong feature</th>
<th>conclusions</th>
</tr>
</thead>
<tbody>
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Describe how this exercise relates to the Scientific Method.