Name: ______________________________________ Date: ________________________

Guided Learning: Science and Testability (Part 5)

Predication and testability… a closer look
The proposed reasons for why one candle went out before the other highlight standard obstacles scientists face when attempting to test explanations. As a reminder, the four were:

I. The book is correct. Candles do go out when they consume all the oxygen, but there is a small random factor, so one candle may go out a little before the other. In your friend's experiment, the shorter one burned longer owing to chance.

II. The shorter candle was made by a more skilled candle-maker, so it burned longer.

III. Flames give off steam, which condenses to form water droplets at the top of the jar. While your friend was wiping the wax off his hand, one of these water droplets fell and extinguished the taller candle, so only the shorter one was still lit when he returned.

IV. The book is wrong. A burning candle gives off carbon dioxide, which accumulates at the top of the jar. This invisible cloud of carbon dioxide eventually expands far enough downward to snuff out the candle. So, the taller candle gets snuffed out first.

There is an element of uncertainty in all experiments and observations. This means explanations based on chance, like explanation I, must always be initially considered. The simple way of determining whether an observed relationship is due to chance is to repeat the experiment several times. If you run 10 identical trials and the taller candle goes out first every time, it is unlikely to be a chance event. This is especially true if the results of those trials are all similar. For example, if the taller candle burned for 10–12 seconds every time and the shorter candle burned for 14–16 seconds each time, it suggests there is a real pattern.

Quick check: you are talking two friends at lunch. One says, "I have a lucky penny. I flipped it 100 times yesterday, and it came up 'heads' 70 of those 100 tosses." The other friend says, "I did something similar yesterday, and my penny is even better. I tossed it 10 times, and it came up 'heads' 8 of those times."

Assuming both your friends are telling the truth, which result do you find more significant? Why?

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Explanation II is more difficult to assess. One problem is that the taller candle was stolen, so it is impossible to test it against other candles made by other craftsmen. However, it is possible to test whether candles made by certain candle-makers burn longer than candles made by others, but that gives only a small amount of support to explanation II.

Furthermore, the term ``more skillfully made'' is not very specific. You could do any experiment and explain the results by saying one candle was ``more skillfully made" than another. If one candle burns hotter, you could say it was more skillfully made because it produces more light and heat. But if it burns cooler, you could claim that it was specifically designed that way to be safer. Whatever results you find, you could always just say the candle-maker purposefully designed the candle to act in that fashion. You are *explaining things after the fact* using reasoning that could account for any results. (This is similar to the "Samoa is very intelligent and is trying to puzzle you" explanation from the earlier parts of this unit. Because it is so imprecise, the ``more skillfully made'' explanation could be criticized for not being falsifiable.)

Reinforcement Check: In part IV of this guided learning, you learned of another reason why explanations are more reliable if they use precise language and call for specific predictions. What was this other reason?

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(After completing this question, check your answer with your teacher and correct it if necessary.)

The third explanation has problems of a different sort. It attributes the observation to a historical event that cannot be recreated. You could investigate it as a detective might and determine that the explanation is plausible. For example, you can confirm that candles give off steam which condenses at the top of the jar, and you could try to determine how likely it is that a water drop could fall and extinguish a candle, but these investigations are unlikely to be conclusive enough to refute the explanation because it is completely based on a past event that cannot be directly observed. You can determine if the explanation is plausible, but you cannot scientifically test it.

Explanations II and III illustrate real concerns in science because sometimes explanation are based on scant data, assumptions about the past that cannot checked, or imprecise principles. In these cases scientists must be especially careful their explanations make clear predictions. In other words, they have to make sure they are not merely explaining data after the fact. Scientific theories should explain data, but a testable theory must clearly predict specific observations without those observations already being known. For example, a theory in paleontology (the study of prehistoric life) may predict the age of a fossil based on what organism made it or where it was found, and that prediction can be tested using radiometric dating.

The fourth explanation is completely testable. It allows you to explain the original observation, but also gives firm predictions about many different scenarios. For example, it predicts a candle will burn longer in a tall, skinny jar than it will in a short, wide one. This allows the explanation to be tested using a completely different setup than the one providing the original observation (where both candles were in the same jar.)

Recall that scientists gain more confidence in an explanation if it is supported by the results of a wide variety of different experiments.

> The most reliable explanations are those that make accurate, explicit predictions for a wide array of experiments.

Unit recap
In this unit you have learned that explanations vary in their testability:

- A scientific explanation must be falsifiable—there has to be a way of proving it wrong.
- Explanation that use precise terms with well-defined meanings are more testable than vague ones that can be applied or interpreted in different ways to match different data.
- A fully scientific explanation must produce explicit predictions rather than merely explain observations after the fact.
- An explanation that predicts observations in a wide variety of situations can be tested more rigorously than one that can only be applied to a limited set of contexts.

You have also discovered some key facts about scientific testing:

- A test whose results are compatible with few explanations is more compelling than one whose results are compatible with many different explanations.
- One way to gain confidence in a test's results is to repeat it several times.
- When comparing two explanations, a test that supports one does not necessarily disprove the other. A test can also refute one explanation without supporting the other.
- Scientists control experiments to narrow down the explanations that successfully account for the results. The more things that change between one observation and the other, the harder it is to pinpoint the reason for any differences in their results.

Putting it all together
A scientific **theory** is a system of beliefs, normally incorporating several hypotheses, that can be applied to explain a variety of observations. Isaac Newton hypothesized, “Objects in motion continue moving in the same direction with the same speed unless a net force acts upon them.” This conflicted with Galileo’s belief that objects moving in circles naturally stay moving in circles.

Isaac Newton realized that his hypothesis, “Objects in motion continue moving in the same direction with the same speed unless a net force acts upon them,” made no sense in light of Earth's orbital motion. Earth and the other planets did not move in straight lines, yet there was no visible forces causing them to curve. To address this, Newton included in his theory of motion a hypothesis that every object in the universe attracts every other object in the universe by an unseen force—gravity. This hypothesis permitted an explanation for the planets' curved pattern of motion.

Newton's hypothesis about gravity was extremely controversial because he gave no explanation for the force. Furthermore, gravity was so weak that it could not be observed in laboratories of his day. It would be over a hundred years before Henry Cavendish successfully verified the existence of gravitational force between test masses in his laboratory. For decades, many scientists refused to accept Newton's theory of motion. However, eventually scientists everywhere accepted Newton's theory because it was applied to successfully predict many different observations.

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1. Describe why Newton's theory of motion is a testable system based on the statements bulleted in the Unit Recap section.

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2. **Challenge**: Newton's theory of motion incorporates five hypotheses:

- Objects at rest stay at rest unless a net force acts upon them.
- Objects in motion continue moving in the same direction with the same speed unless a net force acts upon them.
- The acceleration caused by a force acting on an object is directly proportional to the size of the force and inversely proportional to the object's mass.
- For every force there is an equal and opposite reaction force.
- Between any two objects in the universe, there exists an attraction called *gravity* that is directly proportional to the masses of the objects and inversely proportional to the square of their separation.

In your journal, on a separate piece of paper, or in an interactive notebook, explain whether each hypothesis above could be tested separately or if some of the hypotheses could only be tested as parts of the greater theory.