TOPIC 2.1: MODELS, LAWS, AND THEORIES

Students will be able to:

S3P-2-01 Use a mystery container activity to outline the relationships among observations, inferences, models, and laws.

S3P-2-02 Plan and perform an experiment to identify a linear pattern between two variables and state the pattern as a mathematical relationship (law).

Include: visual, numeric, graphical, and symbolic modes of representation

S3P-2-03 Describe the relationships among knowledge claims, evidence, and evidential arguments.

Include: atomic model of matter, a relevant advertising claim

S3P-2-04 Outline the tentative nature of scientific theories.

Include: speculative and robust theories

S3P-2-05 Describe the characteristics of a good theory.

Include: accuracy, simplicity, and explanatory power

GENERAL LEARNING OUTCOME CONNECTION

Students will...

Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop (GLO A2)

SPECIFIC LEARNING OUTCOME

S3P-2-01: Use a mystery container activity to outline the relationships among observations, inferences, models, and laws.

SUGGESTIONS FOR INSTRUCTION

Notes to the Teacher

For background information, refer to "Understanding Models, Laws, and Theories" included in Appendix 2.1: Wave-Particle Model of Light—Models, Laws, and Theories, or see McComas' article on the "Ten myths of science."

Class Activity

Use a rotational graffiti activity (see *Senior Years Science Teachers' Handbook*, page 3.21) to tap into students' prior knowledge of scientific models, laws, and theories. Questions that students could address in this exercise are:

1. What is a scientific model? Give examples.
2. What is a scientific law? Give examples.
3. What is a scientific theory? Give examples.
4. Is it possible to prove scientific theories?
5. Do you believe in atoms? Why?
6. How are science and art similar and/or different?
7. Some astronomers say the universe is expanding, some say it is shrinking, and others say it is static. How can these scientists arrive at completely different conclusions when they look at the same evidence?
8. Can scientific theories change?

(For more information, see Lederman et al. in the Suggested Learning Resources.)

Laboratory Activities

Students use a mystery container and design a model that explains their observations of the movement and sounds of the objects in the container. Students should differentiate between their observations (their sense data) and their inferences (the meaning they assign to their observations). See Appendix 2.2: The Mystery Container for a mystery container activity.

- Observations: Rolling, sliding, clunking noises are heard.
- Inference: A cylinder rolls one way and slides the other.
- Law: Establish the meaning of a scientific law by first noting regular patterns in observations. The statement "whenever I hold the mystery container upright and rotate it to the left, I hear a rolling sound and then a clunk as the object hits the side wall" is a simple qualitative law that has constraints on it (the way you must hold the container).
- Model: There is a metal cylinder inside the container that is free to move.

SKILLS AND ATTITUDES OUTCOMES

S3P-0-1a: Explain the roles of theory, evidence, and models in the development of scientific knowledge.

S3P-0-1e: Differentiate between how scientific theories explain natural phenomena and how scientific laws identify regularities and patterns in nature.

GENERAL LEARNING OUTCOME CONNECTION

Students will...

Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop (GLO A2)

SUGGESTIONS FOR INSTRUCTION

- Prediction of the model: If I rotate the container rapidly, the cylinder should tumble.
- Test the model.

Teacher Demonstration

Ask students to extend their understanding of observations, inferences, models, and laws to scientific phenomena that they have previously studied. For example:

- Rub a plastic rod with silk and bring it near a fine stream of water.
- Rub the edge of a stemmed glass with a moistened finger (friction creates a standing wave in glass that increases in intensity).
- Recall how an earthquake in Ontario can make glasses in a cupboard in Manitoba move (energy is transmitted from one place to the other in the form of seismic waves).

Senior Years Science Teachers' Handbook Activities

Students complete Compare and Contrast Frames using laws and models, observation, and inference.

Students can use Concept Frames to define terms and include examples from science.

SUGGESTIONS FOR ASSESSMENT

Observation

Students prepare a container containing a mysterious object and exchange it with a partner. Students note in their scientific journals the stages followed to arrive at a model explaining the identity of the object.

SUGGESTED LEARNING RESOURCES

See Appendix 2.2: The Mystery Container

References

McComas, W.F. (1996) “Ten myths of science: Reexamining what we think we know about the nature of science.” *School Science and Mathematics* 96: 10–16.

Lederman, Norm G., Fouad Abd-El-Khalick, Randy L. Bell, Renée S. Schwartz. (June 6, 2002) “Views of nature of science questionnaire: Toward valid and meaningful assessment of learners’ conceptions of nature of science.” *Journal of Research in Science Teaching* 39.6: 497–521.

GENERAL LEARNING OUTCOME CONNECTION

Students will...

Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop (GLO A2)

Specific Learning Outcome

S3P-2-02: Plan and perform an experiment to identify a linear pattern between two variables and state the pattern as a mathematical relationship (law).

Include: visual, numeric, graphical, and symbolic modes of representation

SKILLS AND ATTITUDES OUTCOMES

S3P-0-1e: Differentiate between how scientific theories explain natural phenomena and how scientific laws identify regularities and patterns in nature.

SUGGESTIONS FOR INSTRUCTION

Notes to the Teacher

The emphasis in Senior 3 Physics is on linear relationships. Students have previously studied linear relationships in Senior 2 mathematics. They should be expected to extend their understanding of concepts such as slope and area to physical relationships.

This is a good time to reinforce the ideas about scientific laws developed in the previous outcome. Students should understand that laws represent patterns in nature, that laws are not absolute, and that they can be constrained by certain conditions such as temperature, pressure, and material.

Student Activity

Students reflect on the regularities observed in Senior 2 Science, such as in Newton's Second Law (force ∝ mass) and for braking distance ($d \propto v^2$). Students differentiate between linear and non-linear patterns.

Student Activity

Students plan and carry out a simple experiment to determine a linear relation between two variables. The teacher may select from any number of possible experiments. For example:

- Astronomy with a Stick (see Appendix 2.3)
- The lengthening of a spring according to the suspended mass (Hooke's Law)
- The relationship between circumference and diameter of a circle
- The relationship between the metre stick shadow and the height of the stick (should be done from January to May or August to November—see Appendix 2.3: Astronomy with a Stick). The same activity can be performed in groups, where each group takes measurements at different times during the day. Compare the results of each group. Explain the differences in slope of the linear graphs of these relationships.

SKILLS AND ATTITUDES OUTCOMES

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2f: Record, organize, and display data, using an appropriate format.

Include: labelled diagrams, tables, graphs

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

GENERAL LEARNING OUTCOME CONNECTION

Students will...

Demonstrate appropriate scientific inquiry skills when seeking answers to questions (GLO C2)

SUGGESTIONS FOR INSTRUCTION

The experimental procedure should be left to the students, who should be able to represent the relationship in the four modes of representation. The teacher acts as a facilitator and re-examines the experimental plan with the pupils and helps them make the necessary modifications.

Students reflect on how scientists use the four modes of representation.

SUGGESTIONS FOR ASSESSMENT

Asking and Answering Questions Based on Data/Performance Assessment

Students visually, numerically, and graphically represent familiar formulas such as $A = l \cdot w$, $C = 2\pi \cdot r$, $D = M/V$, $V = l \cdot w \cdot h$, and $A = \frac{1}{2} b \cdot h$ (for a constant base).

Lab Report Assessment

Laboratory Report Rubric, Appendix 5

SUGGESTED LEARNING RESOURCES

Appendix 2.3: Astronomy with a Stick

Appendix 5: Developing Assessment Rubrics in Science

GENERAL LEARNING OUTCOME CONNECTION

Students will...

Recognize both the power and limitations of science as a way of answering questions about the world and explaining natural phenomena (GLO A1)

SPECIFIC LEARNING OUTCOME

S3P-2-03: Describe the relationships among knowledge claims, evidence, and evidential arguments.

Include: atomic model of matter, a relevant advertising claim

SUGGESTIONS FOR INSTRUCTION

Notes to the Teacher

A knowledge claim is a declaration of conviction consisting of a sentence of the type "I know that..." or "I believe that...." Knowledge claims are supported by evidence whose nature depends on the training and the experiment of the claimer. Evidence can be first-hand observations, deference to authority, or plausible explanations. Deference to authority can range from naive acceptance of the authority to a more careful consideration of evidence. While we would prefer that students generate as much of the evidence as they possibly can, in science it is not always feasible to do so. Experiments need specialized equipment, some experiments are dangerous, and so on. However, we should still encourage students to evaluate the evidential claims made by authority. Is the evidence plausible? Does it relate to my personal experience? Could I do the experiment myself? Can I model the experiment? We wish to address the questions, "What makes us believe?" and "How do I know?"

To be convincing, the claimer must formulate an argument relevant to the intended audience. Sometimes the evidence is given in the form of a critical experiment that is overwhelmingly convincing.

Students examine an example of scientific reasoning drawn from everyday experience. For example, you are discussing carbonated beverages with your friend when she makes the following claim: "I believe that Dr. Pop is the best." You are not convinced and ask her to support her opinion with evidence. To convince you, she should choose evidence that is relevant to you. Her evidence might be based on an authority such as "Céline Dion recommends this product"; it could be statistical data, such as "three out of four people prefer Dr. Pop"; or she could provide a biochemical explanation that this product contains less caffeine and less sugar and is therefore better for one's health. Discuss such examples by underlining the elements of the scientific reasoning.

SKILLS AND ATTITUDES OUTCOMES

S3P-0-1d: Describe how scientific knowledge changes as new evidence emerges and/or new ideas and interpretations are advanced.

S3P-0-3b: Describe examples of how technology has evolved in response to scientific advances, and how scientific knowledge has evolved as the result of new innovations in technology.

GENERAL LEARNING OUTCOME CONNECTION

Students will...

Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop (GLO A2)

SUGGESTIONS FOR INSTRUCTION

Follow up the everyday example with a scientific claim students are familiar with from their previous experiences. The atomic model of matter is a good example:

- Knowledge Claim: The atom has a positive nucleus surrounded by negative electrons.
- Evidence: Rutherford's experiment refuted Thomson's plum pudding model. By bombarding a thin gold foil with alpha particles, Rutherford showed that the matter consists of a positive nucleus in a rather large, empty space, surrounded by negative charges. Rutherford's experiment might be considered a critical experiment because it involved the widespread acceptance of this model and the rejection of Thomson's model.

Senior Years Science Teachers' Handbook Activities

Students complete Compare and Contrast Frames about evidence and evidential arguments used in science versus evidence and evidential arguments used in legal practice.

SUGGESTIONS FOR ASSESSMENT

Recognizing the Role of Evidence

Choose a paragraph in a scientific textbook and ask students to identify a knowledge claim, evidence, and evidential argument. Often the evidence is given in the form of more claims. Students suggest ways these claims can be confirmed.

SUGGESTED LEARNING RESOURCES

See Appendix 2.1: Wave-Particle Model of Light—Models, Laws, and Theories

Stinner, A., and H. Williams. (1993) "Conceptual Change, History, and Science Stories." *Interchange* 24.1: 87–103.

GENERAL LEARNING OUTCOME CONNECTION

Students will...

Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop (GLO A2)

SPECIFIC LEARNING OUTCOMES

S3P-2-04: Outline the tentative nature of scientific theories.

Include: speculative and robust theories

S3P-2-05: Describe the characteristics of a good theory.

Include: accuracy, simplicity, and explanatory power

SUGGESTIONS FOR INSTRUCTION

Notes to the Teacher

The word "theory" is used in everyday language to mean many different things, from an idea or hypothesis to a complex explanatory system such as Einstein's Theory of Relativity. In this outcome, the use of the adjectives "speculative" and "robust" helps to differentiate between a public and a scientific understanding of the word "theory."

Speculative theories have little supporting evidence but may be useful in defining questions and establishing a research program. A robust theory is a complex explanatory system that may include presuppositions, empirical evidence, novel predictions, models, and scientific laws.

However, it can never really be proven that a theory will cover all possible cases. (There are far too many to check!) Thus, our theories are tentative and could change in the future to accommodate new information and/or new interpretations of old information. Since theories can and do change, history has illustrated that at times we will have competing theories within the scientific community. Then, how do we evaluate a theory? According to Thomas Kuhn, explanatory theories can be evaluated according to the following criteria (and these are not exhaustive):

- Accuracy: Consequences deducible from a theory should agree with existing experiments and observations.
- Simplicity: A theory should bring order to phenomena that, in its absence, would be individually isolated and confused.
- Explanatory Power: A theory should be consistent with itself and other currently accepted theories. In other words, a theory should not contradict itself or other accepted theories. The consequences of a theory should extend far beyond the particular observations and laws it was initially designed to explain.

In hindsight, we may be inclined to view accuracy as the major selection criterion for theory choice. However, for competing theories, accuracy is a necessary but not usually a sufficient criterion. Copernicus' heliocentric theory was no more accurate than Ptolemy's geocentric theory until Kepler revised it more than 60 years later. Additionally, a theory may be more accurate in one area and less in another.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop (GLO A2)

SUGGESTIONS FOR INSTRUCTION

Theories are also judged by their simplicity and consistency. For example, simplicity favoured Copernicus' system but, in terms of consistency, a moving Earth was inconsistent with Aristotle's explanation of motion. However, in terms of scope, Copernicus' theory was able to make novel predictions such as the existence of the phases of Venus (which was not discovered until 50 years later) to extend the scope of the theory.

Senior Years Science Teachers' Handbook Activities

Students use a Compare and Contrast Frame to outline speculative and robust theories.

SUGGESTIONS FOR ASSESSMENT

Recognizing the Role of Evidence

Students evaluate known theories (atomic models, model of the solar system) using Thomas S. Kuhn's five characteristics of a good theory.

SUGGESTED LEARNING RESOURCES

Kuhn, Thomas. (1977) "Objectivity, Value Judgement, and Theory Choice." *The Essential Tension: Selected Studies in Scientific Tradition and Change*: 320–339.

NOTES