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CANADA

Education, Early Learning and Culture
English Programs

Prince Edward Island Science Curriculum

Science
Grade 9

CURRICULUM

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Foreword

The pan-Canadian *Common Framework of Science Learning Outcomes K to 12* (1997) assisted in standardizing science education across Canada. This framework was used to develop the *Foundation for the Atlantic Canada Science Curriculum* (1998) and the *Grade 9 Atlantic Canada Science Curriculum* implemented in 2003 and revised in 2007. Sections of the *Atlantic Canada Foundation Document* have been incorporated into this revision and augmented with ideas and standards presented in newer Canadian provincial science curricula and recent literature concerning science education. This includes the National Research Council's *Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas* (2012), and the resulting *Next Generation Science Standards: For States, By States* (2013).

The revised science curriculum is designed to enable students to work towards the achievement of six, cross-curricular essential graduation competencies (EGCs) as defined by the Council of Atlantic Ministers of Education and Training (CAMET) in *The Atlantic Canada Framework for Essential Graduation Competencies* (2015). To facilitate this shift to competency-based education, a number of significant changes have been incorporated in this guide: 1) specific curriculum outcomes (SCOs) have been reduced and targeted toward EGCs; 2) greater emphasis has been placed on processes and skills; 3) achievement indicators (AIs) have been included to clarify the "depth and breadth" of SCOs; and 4) links between science outcomes and those of other subject areas have been identified to facilitate integration.

This document replaces earlier versions of the Grade 9 Science curriculum and provides Prince Edward Island teachers with an updated outcomes framework for science.

VISION

The Prince Edward Island science curriculum is guided by the vision that all students will have the opportunity to develop scientific literacy. Scientific literacy is the set of knowledge, skills, and attitudes that enables an individual to critically evaluate and make well-informed decisions regarding science-related claims, issues, and applications.

Scientific Literacy

As we progress through the 21st century, humans have created a world that confronts us daily with issues of a scientific and technological nature: global warming, decreasing sources of clean water, cloning, multi-drug-resistant bacteria, evolving viruses, nanotechnology, genetically modified organisms (GMOs), waste disposal, new sources of energy, dependency on electronic devices, suburbanization, and new frontiers in space exploration. In order to play an active role in this world of change, individuals must have a degree of scientific literacy that enables them to sort through valid and invalid claims and understand the implications of new developments.

Scientifically literate people have a fundamental knowledge about the natural world around them and an understanding of the scientific processes that were used to obtain such knowledge. They are aware that knowing something scientifically requires evidence that passes through a rigorous process of review, evaluation, and support by a global community of experts, and that this process extends over time. They recognize our understanding of the natural world is not static but constantly evolving; what we “know” today may change as new concepts and technologies are developed. Whether or not they work in a science-related field, scientifically literate people are able to make informed personal, political, economic, and ethical decisions regarding science and technology matters by evaluating evidence, and are able to defend their decisions using rational reasoning.

Aim

The Prince Edward Island science curriculum aims to facilitate the development of scientifically literate students by providing opportunities to

- develop and apply an understanding of the nature of science to evaluate claims related to science;
- develop skills and strategies required to perform scientific inquiry and apply science to solve problems;
- work collaboratively to generate and explore ideas, and carry out investigations;
- reason scientifically;
- develop foundational understanding of scientific concepts that explain the natural and material world;
- communicate scientific information effectively;
- evaluate the personal, societal, environmental, and ethical implications of the applications of science and technology from a variety of perspectives.

Attitudes

Positive attitudes towards science will also be fostered in our learners. Attitudes are generalized aspects of behaviour that can be modelled by adults and encouraged by selective approval. Positive attitudes include, but are not limited to

- exhibiting a sense of wonder and curiosity about scientific and technological endeavours;
- engaging and persevering in science tasks and projects;
- demonstrating resilience;
- showing concern for safety during inquiry activities;
- exhibiting collaborative behaviours;
- valuing the role of science and technology in our understanding of the world;
- demonstrating an appreciation of the nature of science;
- demonstrating respect and sensitivity in maintaining a balance between the needs of humans and the environment;
- being open-minded and projecting beyond the personal consequences of proposed actions.

Essential Graduation Competencies (EGCs)

Curriculum is designed to articulate what students are expected to know and be able to do by the time they graduate from high school. The PEI Department of Education, Early Learning, and Culture designs curriculum that is based on the *Atlantic Canada Framework for Essential Graduation Competencies* released by the Council of Atlantic Ministers of Education and Training (CAMET) in 2015.

Competencies articulate the interrelated sets of attitudes, skills, and knowledge—beyond foundational literacy and numeracy—that prepare learners to successfully participate in lifelong learning and life/work transitions. They are cross-curricular in nature and provide opportunities for interdisciplinary learning. Six competencies have been identified by CAMET: citizenship, communication, personal-career development, creativity and innovation, critical thinking, and technological fluency (Figure 1). Achievement of the essential graduation competencies (EGCs) will be addressed through the assessment and evaluation of curriculum outcomes developed for individual courses and programs.

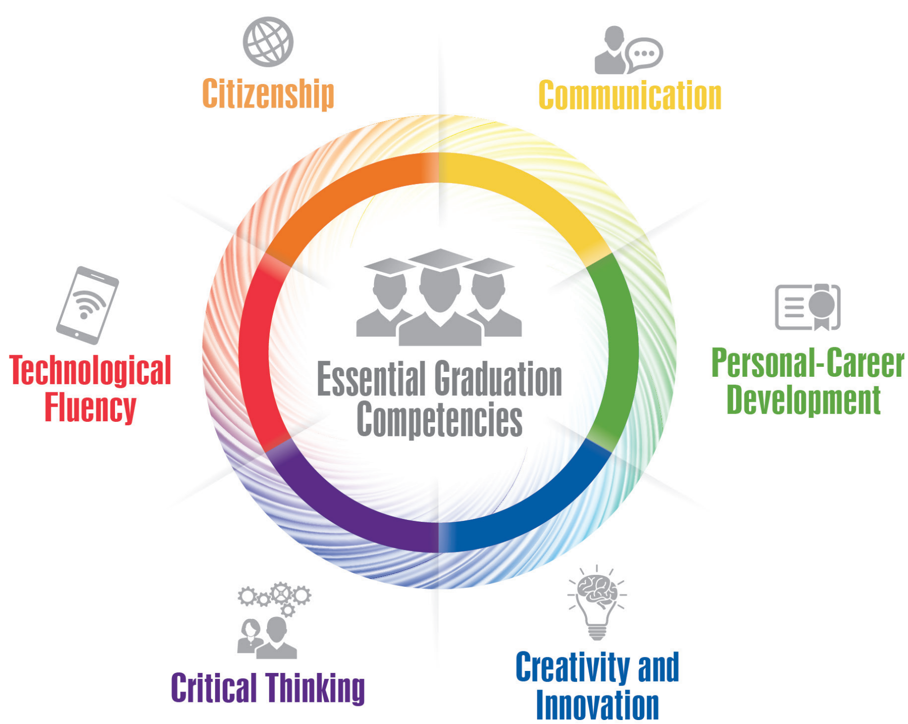


Figure 1. Essential graduation competencies

Program Design and Components

Critical Thinking
Learners are expected to analyze and evaluate evidence, arguments, and ideas using various types of reasoning and systems thinking to inquire, make decisions, and solve problems. They reflect critically on thinking processes.

Technological Fluency
Learners are expected to use and apply technology to collaborate, communicate, create, innovate, learn, and solve problems. They use technology in a legal, safe, and ethically responsible manner.

Citizenship
Learners are expected to contribute to the quality and sustainability of their environment, communities, and society. They analyze cultural, economic, environmental, and social issues; make decisions and judgments; and solve problems and act as stewards in a local, national, and global context.

Communication
Learners are expected to express themselves and interpret effectively through a variety of media. They participate in critical dialogue, listen, read, view, and create for information, enrichment, and enjoyment.

Personal-Career Development
Learners are expected to become self-aware and self-directed individuals who set and pursue goals. They understand and appreciate how culture contributes to work and personal life roles. They make thoughtful decisions regarding health and wellness, and career pathways.

Creativity and Innovation
Learners are expected to demonstrate openness to new experiences; to engage in creative processes; to make unexpected connections; and to generate new and dynamic ideas, techniques, and products. They value aesthetic expression and appreciate the creative and innovative work of others.

Foundations of Scientific Literacy

PEI science curriculum is based upon four foundations deemed essential to scientific literacy. Three of these components–Procedural Knowledge, Content Knowledge, and Decisions and Perspectives–reflect 1) the processes and skills required in the development and application of scientific knowledge, 2) the resulting body of knowledge, and 3) the need for critical thinking about the application of science developments from a variety of perspectives and with consideration of ethics. Central to these three foundations is the Nature of Science, which addresses epistemic knowledge or the principles underlying science as a way of knowing. More detail relating to these concepts can be found on pp. 14–25. The foundations of science literacy support and are integrated with the six essential graduation competencies. Problem-solving is considered foundational to science, and is therefore included in Figure 2.

Figure 2. Foundations of scientific literacy

Program Design and Components

General Curriculum Outcomes

General curriculum outcomes (GCOs) for the science curriculum are based upon the four foundations of scientific literacy. GCOs identify in broad terms what students are expected to know and be able to do upon completion of study in science at the time of graduation.

Nature of Science (NoS)
Students will comprehend science as a way of knowing about the natural world that uses valid, empirical evidence and logical reasoning. They will recognize that scientific knowledge is dynamic and probabilistic in its nature, evolving as new evidence and ideas are presented, and accepted by a community of scientists only after rigorous review.

Procedural Knowledge (PK)
Students will understand and become proficient using skills, processes, and practices required for scientific inquiry and the application of science. This includes the skills necessary for reading comprehension, argumentation, communication, collaboration, computational thinking, mathematical analysis, and technological fluency.

Content Knowledge (CK)
Students will integrate knowledge and understanding of concepts related to life sciences, physical sciences, Earth and space sciences, and their real-world applications. They will think critically about these understandings to extend their knowledge of themselves and the world around them.

Decisions and Perspectives (DP)
Students will evaluate personal, societal, environmental, ethical, and sustainability issues relating to the applications of science and technology from multiple perspectives. This includes exploring science-related career pathways.

Specific Curriculum Outcomes

Specific curriculum outcomes (SCOs) state the intended outcomes of instruction and identify what students are expected to know and be able to do for a particular course. SCOs provide the goals or targets of the prescribed education program referenced in 71(a) of the *PEI Education Act*. They provide a focus for instruction in terms of measurable or observable student performance and are the basis for the assessment of student achievement across the province. PEI specific curriculum outcomes are developed with consideration of Bloom's Taxonomy of Learning (p. 8) and essential graduation competencies (Appendix C, p. 88)

Each specific curriculum outcome is described by a set of *achievement indicators*, that

- support, define, and demonstrate the depth and breadth of the corresponding SCO;
- are not a mandatory checklist, prioritized list of instructions, or prescribed assessment items;
- can be used to guide the development of success criteria and assessment.

Elaborations provide a fuller description and the instructional intent of each SCO. They may describe the context, specific examples, or further background information to help teachers gain a deeper understanding of the SCO.

Bloom's Taxonomy

In 1956, Bloom et al. published a framework for the purpose of classifying expectations for student learning as indicated by educational objectives (outcomes).[13] This unidimensional framework of cognitive processes became known as Bloom's Taxonomy. David Krathwohl's 2002 revision of this taxonomy introduced a second dimension, the knowledge dimension, that classified the type of knowledge described by an outcome. To fully understand an SCO, it is important to understand how the learning is representative of both the cognitive process and knowledge dimensions.

Cognitive Process Dimension

The cognitive process dimension shown in Table 1 represents a continuum of increasing cognitive complexity ranging from lower order thinking skills (i.e., recalling to applying) to higher order thinking skills (i.e., analyzing to creating). Higher order thinking skills are involved when students are critically thinking and problem-solving. The **verb** that begins a specific curriculum outcome represents the cognitive process dimension.

Explanation of Cognitive Process	Example Verbs
Remembering Retrieve relevant knowledge from long-term memory; recall.	define, label, list, match, name
Understanding Construct meaning from instructional messages including oral, written, and graphic communication.	compare, describe, discuss, distinguish, explain, interpret, summarize
Applying Carry out or use a procedure in a given situation.	apply, build, classify, calculate, construct, interpret, graph, perform, record, solve, use
Analyzing Break material into constituent parts and determine how parts relate to one another and to an overall structure or purpose. Make inferences and find evidence to support generalizations.	analyze, categorize, classify, compare, contrast, deduce, differentiate, distinguish, examine, group, investigate, organize, relate, sort
Evaluating Make judgments based on criteria and standards.	argue, defend, evaluate, judge, justify, prioritize, rate, recommend, select
Creating Put elements together to form a coherent or functional whole; generate new ideas, products, or ways of viewing; reorganize elements into a new pattern or structure.	compose, construct, create, design, formulate, hypothesize, invent, predict, synthesize

Table 1. The cognitive process dimension and associated verbs

Knowledge Dimension

The knowledge dimension (Table 2) classifies four types of knowledge, ranging from concrete to abstract, that learners may be expected to acquire or construct. These types of knowledge include factual, conceptual, procedural, and metacognitive. The **noun** included in a specific curriculum outcome represents the type of knowledge or the knowledge dimension.

Knowledge Dimension	Description
Factual The basic elements students must know to be acquainted with a discipline or solve problems **KNOWING THAT**	• knowledge of terminology (e.g., technical vocabulary) • knowledge of specific details and elements (e.g., characteristics of the Tundra biome)
Conceptual The interrelationship among the basic elements within a larger structure that enables them to function together **KNOWING WHAT and WHY**	• knowledge of classifications and categories (e.g., families of elements) • knowledge of principles and generalizations (e.g., Ohm's Law) • knowledge of theories, models, and structures (e.g., Particle Theory)
Procedural How to do something, methods of inquiry and criteria for using skills, algorithms, techniques, and methods **KNOWING HOW**	• knowledge of subject-specific skills and algorithms (e.g., how to graph independent versus dependent variable data) • knowledge of subject-specific techniques and methods (e.g., measuring mass) • knowledge of criteria for determining when to use appropriate procedures (e.g., naming ionic versus molecular compounds)
Metacognitive Knowledge of cognition in general as well as an awareness and knowledge of one's own cognition **KNOWING HOW TO KNOW**	• strategic knowledge (e.g., knowing how how to approach solving a problem) • knowledge about cognitive tasks, including appropriate contextual and conditional knowledge (e.g., awareness of one's own knowledge level)

Table 2. The knowledge dimension

Structure of an SCO

Prior to planning instruction and assessment, it is necessary to examine the structure of a specific curriculum outcome to fully understand its intent. The Bloom's verb in the outcome relates to the expected level and type of thinking (cognitive process). A noun or phrase communicates the type of knowledge (i.e., factual, conceptual, procedural, or metacognitive) that is the focus of the outcome.

cognitive process: CREATE

PK 3 Design an investigation to examine a relationship between variables.

type of knowledge: PROCEDURAL

Taxonomy Table

Combining the cognitive process dimension and the knowledge dimension into one table, a taxonomy table helps teachers to visualize the overall expectations of a course. Codes in Table 3 represent Grade 9 outcomes that can be found on p. 38.

Bloom's Cognitive Process	Knowledge Dimension			
	Factual	Conceptual	Procedural	Metacognitive
Remembering				
Understanding		CK 1, CK 2.1, CK 2.2, CK 3		NoS 1
Applying		CK 1, CK 2.1, CK 2.2, CK 3	PK 1, PK 4, PK 5	
Analyzing		CK 1, CK 2.1, CK 2.2, CK 3, DP 1	PK 6	
Evaluating		NoS 2	PK 7	DP 2, DP 3
Creating			PK 2, PK 3	

Table 3. Taxonomy table for Grade 9 Science

Curriculum Guide Design

Specific curriculum outcomes that address each science foundation are grouped together in this guide. This is to ensure that the foundations of scientific literacy, rather than units of content, are the focus of instruction and assessment. Each outcome is presented on one page, which contains information such as its cognitive level and the essential graduation competencies it supports.

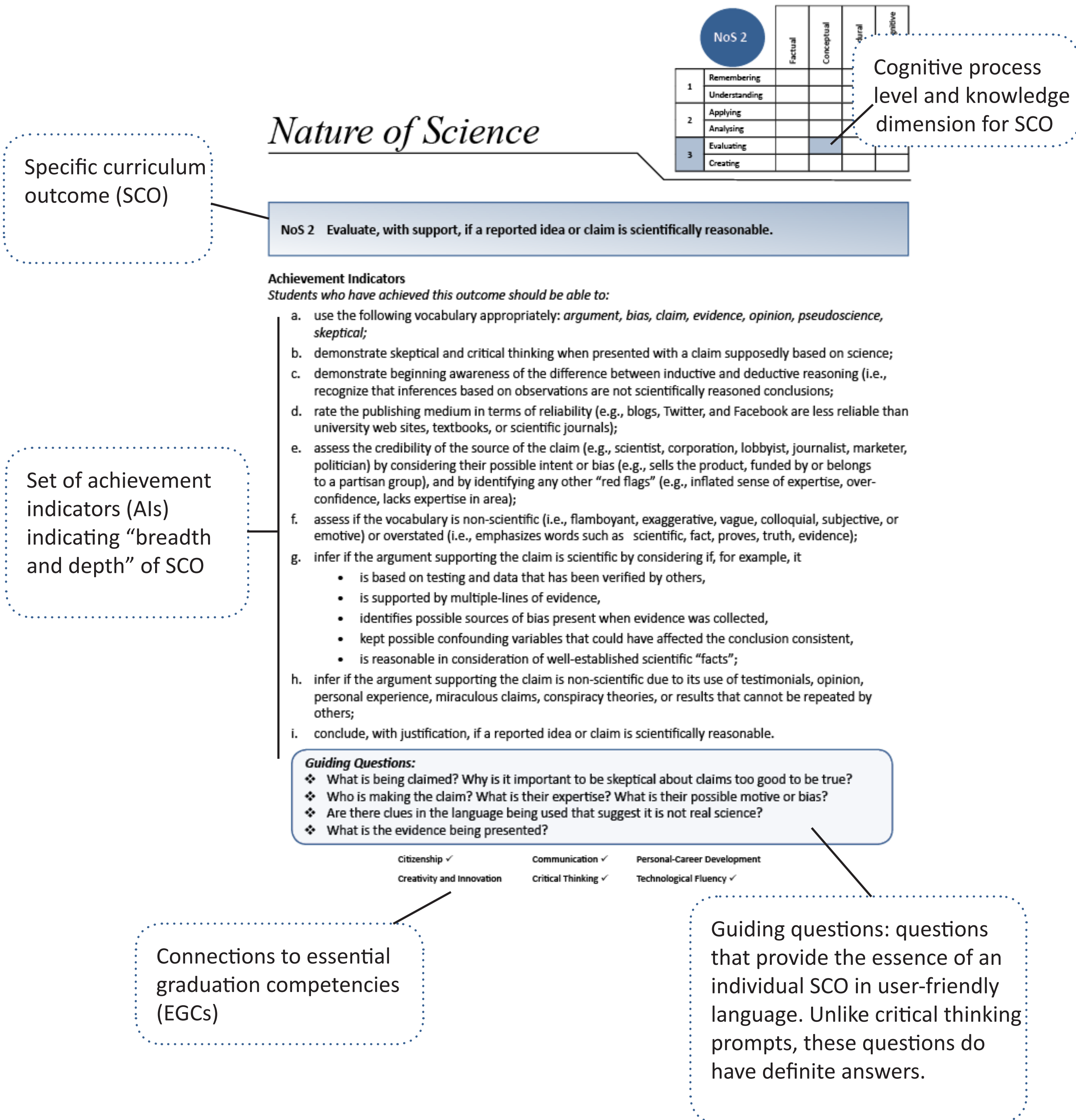


Figure 3. Example page for a specific curriculum outcome and its set of achievement indicators

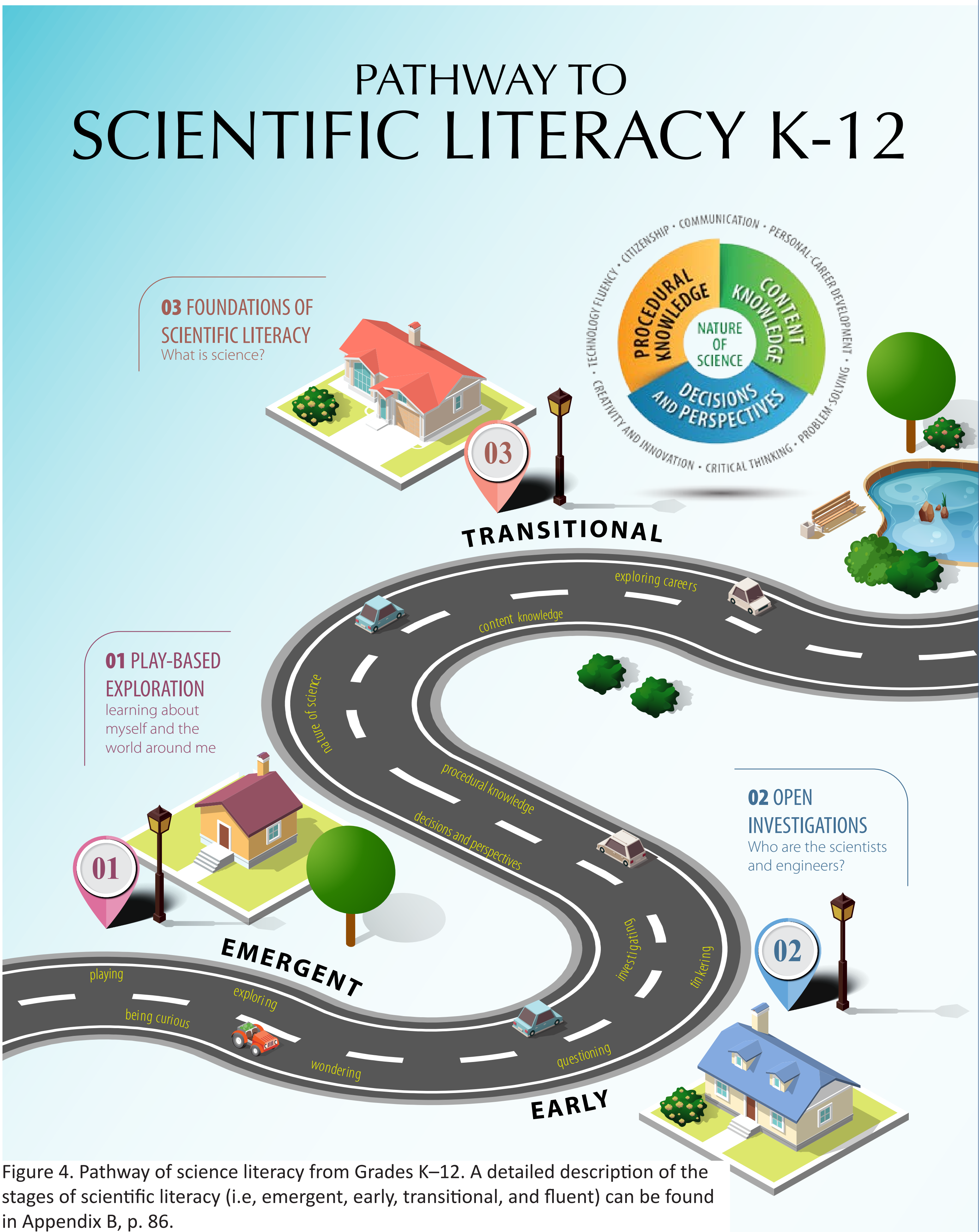
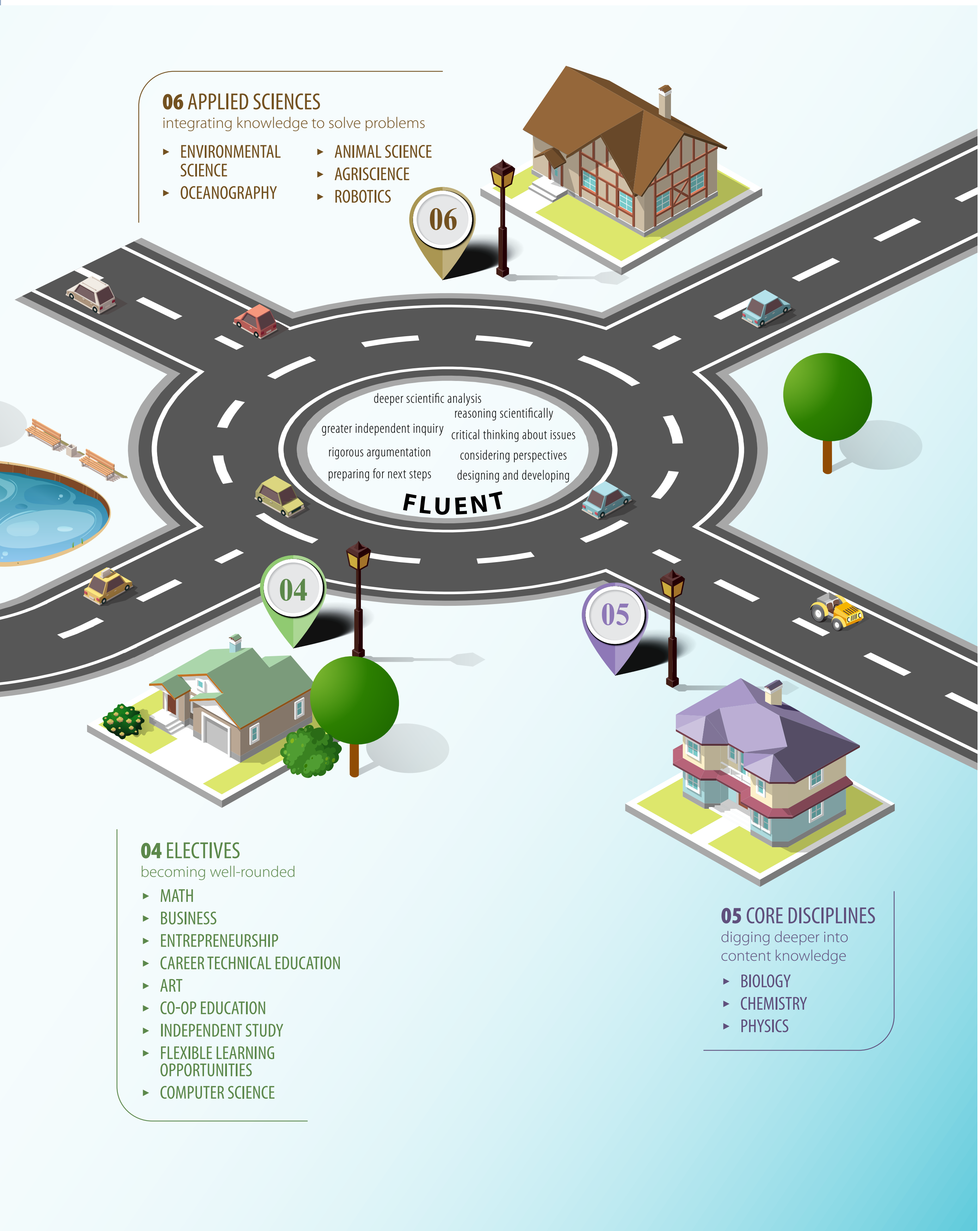


Figure 4. Pathway of science literacy from Grades K–12. A detailed description of the stages of scientific literacy (i.e, emergent, early, transitional, and fluent) can be found in Appendix B, p. 86.


06 APPLIED SCIENCES
integrating knowledge to solve problems
ENVIRONMENTAL SCIENCE
OCEANOGRAPHY
ANIMAL SCIENCE
AGRISCIENCE
ROBOTICS
06
deeper scientific analysis
reasoning scientifically
greater independent inquiry
critical thinking about issues
rigorous argumentation
considering perspectives
preparing for next steps
designing and developing
FLUENT
04
05
04 ELECTIVES
becoming well-rounded
MATH
BUSINESS
ENTREPRENEURSHIP
CAREER TECHNICAL EDUCATION
ART
CO-OP EDUCATION
INDEPENDENT STUDY
FLEXIBLE LEARNING OPPORTUNITIES
COMPUTER SCIENCE
05 CORE DISCIPLINES
digging deeper into content knowledge
BIOLOGY
CHEMISTRY
PHYSICS

Foundations of Scientific Literacy

The four foundations of scientific literacy represent the complex and dynamic relationship of science and society that is depicted in Figure 5. How Science Works. Procedural Knowledge and the Nature of Science are represented in this model by Exploration and Discovery, Testing Ideas, and Community Analysis and Feedback. The final results of science, Benefits and Outcomes, include the theories, models, and laws that help explain natural phenomena and are addressed by content knowledge. The Benefits and Outcomes section of the model also links to the foundation Decisions and Perspectives, since both relate to the application of science in our society.

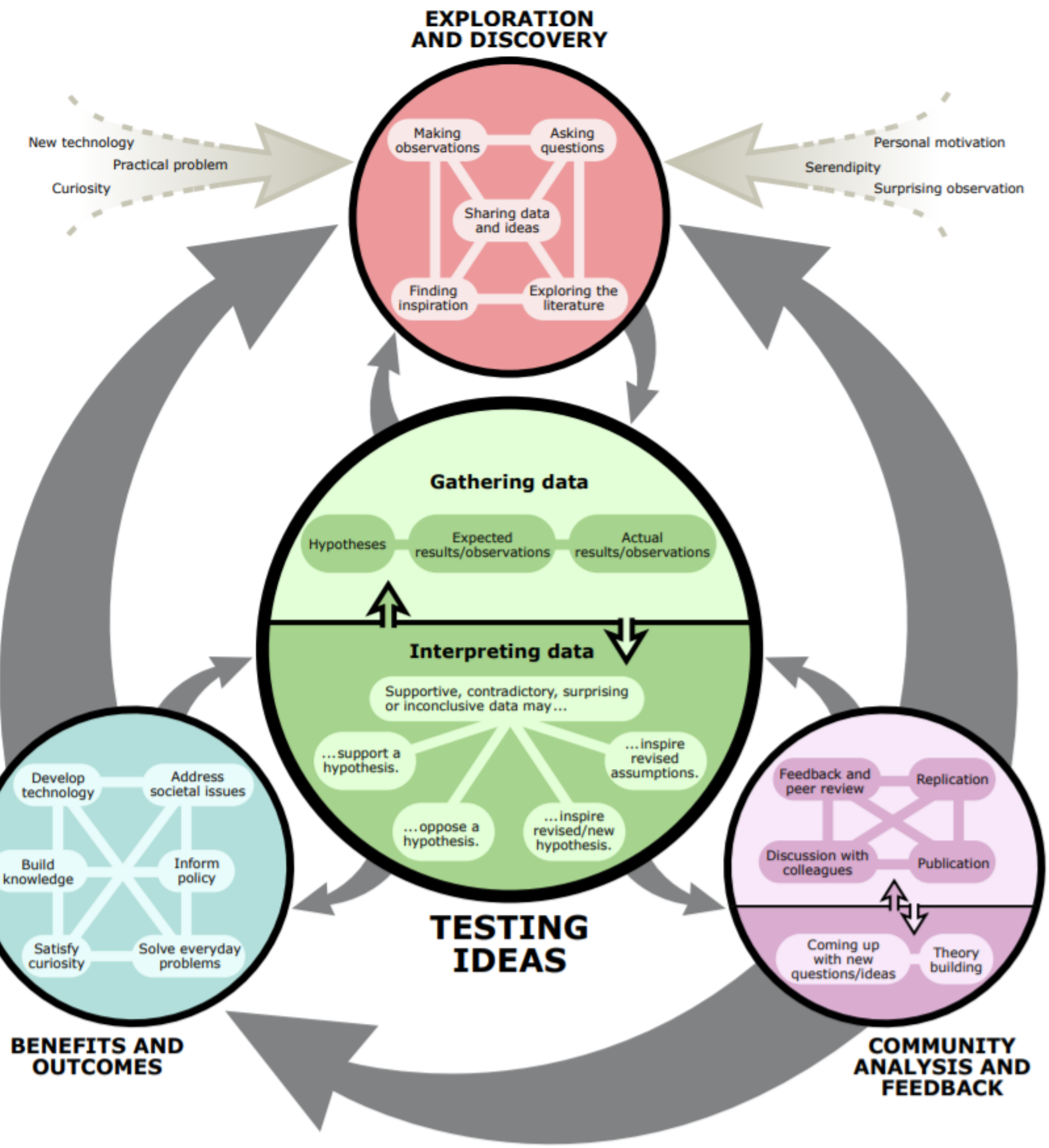


Figure 5. How science works. Reprinted with permission from the University of California Museum of Paleontology, Berkeley, and the Regents of the University of California. Copyright 2015

What is science?

Science originated as a philosophy of nature, and it stems from the curiosity of humans and their ambition to understand themselves and the natural world around them. Science presumes that the world has a natural organization and is coherent; therefore, it can be understood. From the historical beginnings of science, humans have attempted to explain the natural world around them by looking for patterns, trends, similarities, and differences in everything from structure and composition to properties and behaviours.

The branch of philosophy known as epistemology (theory of knowledge) examines knowledge and the *way we know*. Many ways of knowing have been identified—such as faith, intuition, emotion, perception, memory, imagination, and reason.[4,27] Knowing something scientifically involves rational reasoning. It is not the purpose of this science curriculum to rate one way of knowing as superior to another, but instead, enable students to develop the skills necessary to think scientifically. This begins with an understanding of the characteristics and principles of science.

> "Epistemic knowledge includes an understanding of the function that questions, observations, theories, hypotheses, models, and arguments play in science, recognition of the variety of forms of scientific inquiry, and the role peer review plays in establishing knowledge that can be trusted." [21] PISA 2015

Science is Limited and Dynamic

Science is limited to developing knowledge and understanding of the physical world. Science can only address questions that have testable solutions; questions such as those relating to the supernatural, ethics, value, or aesthetics are beyond the scope of science.

The body of knowledge that is produced by science is constantly evolving, and much of our understanding of the world has resulted from a steady and gradual accumulation of knowledge over time. Scientists are always proposing and testing new hypotheses, researching, and building bodies of evidence that can lead to new theories.

Science is never absolute but based upon probability and levels of certainty. However, this does not mean that everything we know as a result of science cannot be relied upon or used to make decisions. Many hypotheses are accepted when it can be shown that there is a 95% probability that the results are not found due to chance; the probability of some studies is higher (e.g., 99%) and approaches, but never reaches, 100%. It takes many studies, each stemming from a hypothesis, and each passing through a rigorous review process, before the scientific community supports the acceptance of a new theory. By the time a theory is accepted, often decades of scientific studies have contributed to its acceptance.

Science is Evidence-Based

Although the practices and types of studies used by scientists to interpret and describe our world are quite varied (Figure 7, p. 19), the knowledge they create is considered scientific when it is based on valid empirical evidence. Empirical evidence is qualitative or quantitative observations (data) recorded using human senses or technology; raw data must analyzed and interpreted before it is considered evidence. The evidence used to support scientific claims may or may not result from experimentation.

Evaluating Evidence

- Is it relevant?
- Is it plausible?
- Is it sufficient?
- Is it reliable?
- Is there bias?
- Is it replicable?

Science Involves Rational Reasoning

The development of scientific claims and theories is characterized by an interplay between inductive and deductive reasoning. *Inductive reasoning* occurs when generalizations or inferences are made based upon observations. When scientists use generalizations to predict what will happen during a test or experiment, they are practising *deductive reasoning*. While inferring and inductive reasoning are important aspects of science, students should recognize that making a conclusion without testing and using deductive reasoning is "jumping to a conclusion" (Figure 6) and is not "scientific thinking." Engaging students in reasoning and argumentation in defense of their claims or conclusions is central to the development of critical thinking in science.

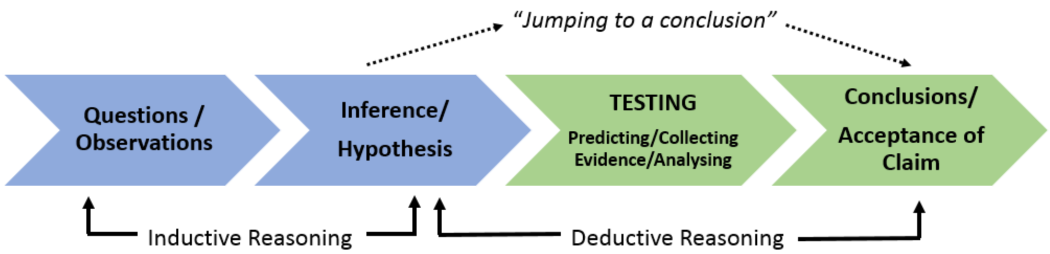


Figure 6. Scientific reasoning

Science Language is Precise

Words commonly used to denote absolutes (e.g., all, none, never) are avoided in scientific communication to reflect that science cannot give complete certainty. Even *fact*, a statement of absolute truth in lay language, is used differently in science. This is also true for the terms *hypothesis*, *law*, and *theory*.

- A *fact* is a readily verifiable *observation* that is generally accepted (e.g., if you drop a coin from your hand, it will fall to the Earth). Facts in science are still open to inquiry and therefore able to change.

- *Hypotheses* are tentative explanations describing a causal relationship. Hypotheses are not guesses but stem from problems, questions, observations, logic, other hypotheses, and theories. The development of a hypothesis involves elements of curiosity, creativity, imagination, and intuition. Hypotheses lead to predictions of what will happen under a given set of circumstances (i.e., tests or investigations). Hypotheses can be accepted, rejected, or modified as a result of evidence. While hypotheses can never be proven true with 100% certainty, they can be proven to be false. Many varied hypotheses can be generated from one new scientific idea.

> "Hypotheses are created, not discovered, and the process of their creation is just as open-minded as the process of artistic creation."[27] Schick and Vaughn

- A *law* is a descriptive generalization, often mathematical, that concerns patterns of behaviour regarding some aspect of the natural world. Laws differ from theories in that they are not explanations; they are similar in that both can be used to make predictions. It is a misconception that laws evolve from theories. It is also a misconception that laws are more credible than theories because they are definite and cannot be altered. Laws, like theories and hypotheses, can be rejected or modified as new evidence is found.

Examples of Laws

Laws of thermodynamics
Law of natural selection
Ohm's law
Coulomb's law
Universal law of gravitation

- A *scientific theory* is more than a passing, tentative suggestion, as is suggested by its use in common language. A theory, as it is used by scientists, is a well-substantiated explanation for a broad set of phenomena within the natural world. A theory synthesizes hypotheses, laws, principles, and facts from a broad range of studies and can involve a variety of fields. In addition to their ability to predict new and a diverse range of phenomena, theories are evaluated in terms of their ability to be tested, their simplicity (how many assumptions are required), and how well they fit into established scientific understandings. Theories maintain acceptance until disproven.

Atomic theory
Germ theory of disease
Big bang theory
Theory of evolution
Theory of general relativity

Science is a Collaborative, Human Endeavour
The science community is global and includes people of all genders, societies, cultures, and ethnicities. While everyone uses science in some way, it is the members of this community who contribute to our deepening understanding of the world. This is due to the fact that scientific research often requires years of training and access to highly specialized equipment and materials that are not at the disposal of the average citizen.

Science is a collaborative process. The proliferation of information that has been generated by this discipline has heightened the need for specialization in increasingly narrower fields. To compensate for this, scientists often work in teams composed of a number of specialists from a variety of fields. Technology has facilitated this collaboration by eliminating the requirement for team members to work in the same geographical location. Online publishing makes the findings of studies available so that investigations can be repeated, critiqued, or developed in new directions. The rigorous process of critical review is frequently completed by peers who have an expertise within the area being studied. Whether by sharing expertise or by providing feedback, collaboration is an essential aspect of science.

Skills and Attitudes for Collaboration

- Considering others' ideas and perspectives
- Criticizing ideas, not people
- Accepting criticism
- Being persuasive
- Listening
- Showing initiative
- Asking for and offering help
- Sharing ideas
- Being responsible, completing tasks
- Taking turns
- Clarifying and asking for clarification
- Following directions

What do scientists do?

The focus of many scientific investigations (studies) is to determine the relationship between variables. Of interest to scientists is 1) Is there a relationship? 2) Is the relationship correlational? 3) Is the relationship causal? In *correlational relationships*, there is an association between the variables. However, it is not known whether or not one causes the other to occur. In *causal relationships*, one variable results in the response or occurrence of another in a consistent manner. Causal relationships can be complex such as is seen with chain reactions, biofeedback mechanisms, and biosphere nutrient cycles. Understanding cause and effect is an important step towards controlling or modifying the cause in ways that address a human need. Often, when a relationship between two variables is assumed to be causal, it is only correlational. Understanding the difference between these two concepts is a fundamental aspect of scientific literacy.

No Relationship, Correlational, or Cause and Effect?

- Smoking and cancer (causal)
- Genetically modified organisms (GMOs) and decrease in biodiversity (no relationship determined)
- Climate change and human activity (complex causal)
- Vaccines and autism (no relationship)
- Megadoses of vitamins and health (correlational)

Correlations can be positive or negative. If the correlation is *positive*, the variables move in the same direction (e.g., an increase in attendance is associated with an increase in achievement). If the correlation is *negative*, a change in direction of one variable is associated with a change in the opposite direction of the other (e.g., an increase in the number of people vaccinated is associated with a decrease in the incidence of a disease–this is also causal). In science, establishing a correlational relationship requires more than observation and inductive reasoning. It requires data collection and statistical analysis, which are used to determine both the direction and strength of the correlation. (e.g., Pearson's correlation coefficient is calculated to measure the linear relationship between two variables.)

Correlational relationships can appear odd, until one remembers that they do not necessarily represent cause and effect. Two examples that demonstrate this are the positive correlation between smoking and alcoholism, and the positive correlation between ice-cream sales and violent crimes. Ice-cream sales do not cause crime. However, correlation may imply a causal relationship and warrant further examination, as was the case with smoking and lung cancer. Smoking was once thought to be beneficial to health. However, the mass production of cigarettes in the early part of the 20th century soon revealed a positive correlation between smoking and lung cancer. The question remained: was tobacco a causative agent?

Is it Cause and Effect?
Based on Hill's postulates

- Does the cause come before effect?
- What is the strength of association (measured by statistics)?
- Is there a consistent association?
- Is there a mathematical relationship between variables?
- Does it make sense in terms of other established science?

Pure causation is extremely hard, and arguably impossible, to prove with 100% certainty. This is due to the fact that real life is complex with a variety of confounding variables that are unable to be completely identified and controlled. Sir Richard Doll and Sir Austin Bradford Hill confirmed the causal link between smoking and cancer in the 1950s. Part of their work involved establishing criteria (Hill's postulates) to increase the strength of causal claims.[22] The more of these postulates that are true for a given relationship, the more likely it is causal in nature. Tools such as Hill's postulates, together with multiple lines of evidence gathered from examination of 7,000 studies over the following decade, resulted in consensus in 1964 that smoking does cause cancer.

Categories of Scientific Studies

One way to classify scientific inquiries is to divide them into two categories: experimental studies and observational studies (Figure 7).[22] In experimental studies, the investigator has control over how the variables are manipulated. For example, in a study on the effect of temperature on the rate of a chemical reaction, the experimenter would manipulate the temperature (cause) and measure the responding change in reaction rate (effect). Confounders such as agitation and the type of chemical would be controlled. These forms of causal investigations are frequently equated with "inquiry" in science education. Observational studies, on the other hand, do not include direct manipulation and control of variables by the experimenter. The preferred study design is best determined by the nature of the question.

Randomized, controlled experimental investigations remain the gold-star method for validating cause and effect phenomena. A familiar type of randomized controlled study is one used in drug trials where some subjects are given the experimental drug to see if it causes an effect. For others, the drug (which is the independent variable) is replaced with a placebo; these subjects are the *control* group and should not experience the effect (dependent variable). If the subject is unaware of which treatment they received, the experiment is considered *blind*. This helps minimize bias that would reduce the quality of the evidence.

Observational studies can be descriptive or analytical in nature. Descriptive observational studies are not directed by a specific question but involve collecting information that may lead to the development of a hypothesis. Analytical-observational examinations, like experimental inquires, are designed to answer a proposed question. However, due to ethical considerations, they do not allow for direct experimentation. Analytical-observational studies can still demonstrate causal relationships with a high degree of certainty when tools such as Hill's postulates are used. To improve their ability to determine cause and effect, analytical-observational investigations rely on methods such as careful design (e.g., use of longitudinal studies) and rigorous statistical control. Observational studies are frequently used in medical research, and appear to be the ones that are most often surrounded by controversy in the media, especially when a cause and effect relationship is suggested.

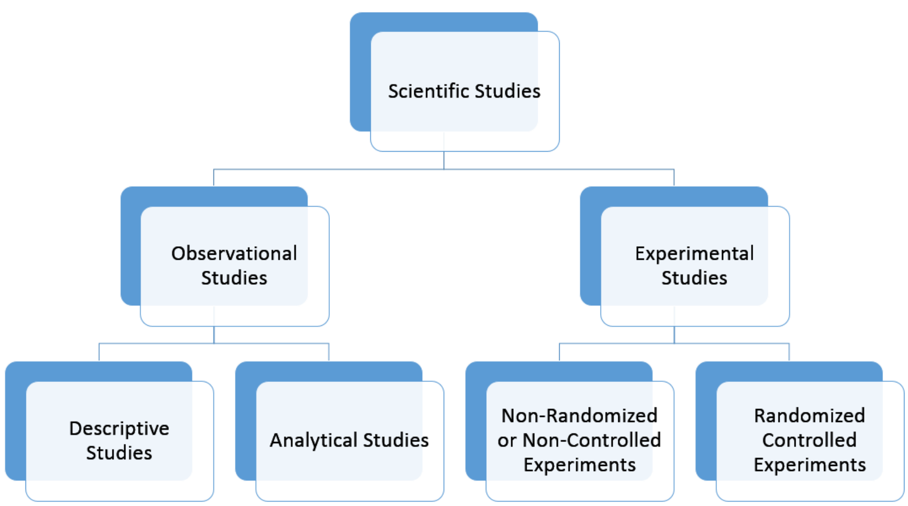


Figure 7. Classification of scientific studies. Adapted from Oleckno, 2002

Modelling: Investigating Complex Systems

A system is a collection of components that interact with one another so that the overall effect is much greater than that of the individual components. Examples of systems are educational systems, political systems, transportation systems, the solar system, the respiratory system, electrical systems, mechanical systems, and ecosystems.

> **"Systems thinking is the ability to see the world as a complex system, where everything is connected to everything else."** [31]
> **J.D. Sterman, Business Dynamics**

Systems thinking is an essential higher order thinking skill that involves thinking about a whole in terms of its parts, and alternatively, about the parts in terms of how they relate to one another and the whole. It involves analyzing the components, dynamics, and the interactions within and between systems. Examining systems in terms of stability, equilibrium, and rate of change is a major focus of both science and engineering.

Models are one tool used by scientists and engineers to help them understand natural and material systems. Models facilitate the understanding of abstract ideas and testing of relationships between variables in complex systems. Models, such as the atomic model, are refined as understanding of a phenomenon evolves.

Scientific models can take many forms. Conceptual models include

- physical replicas (e.g., model of the cell, landforms, water systems of area)
- diagrams that demonstrate the relationship of subatomic particles in the atom (Figure 8)
- flow charts that depict energy flow in a food web (Figure 9) or electricity transmission rates (Figure 10)

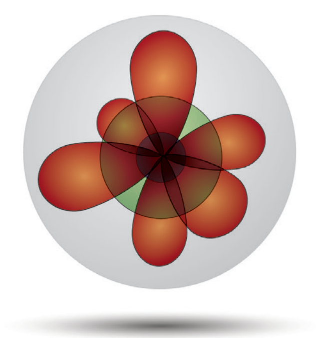


Figure 8. The quantum mechanical model of the atom

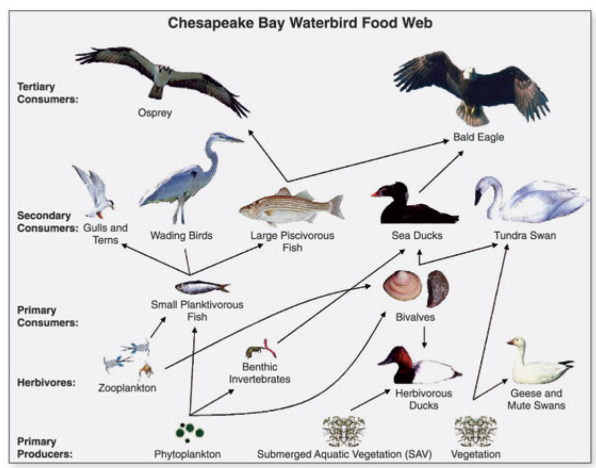


Figure 9. Energy flow in a food web.
Credit: Matthew C. Perry courtesy of the U.S. Geological Survey http://www.usg.gov

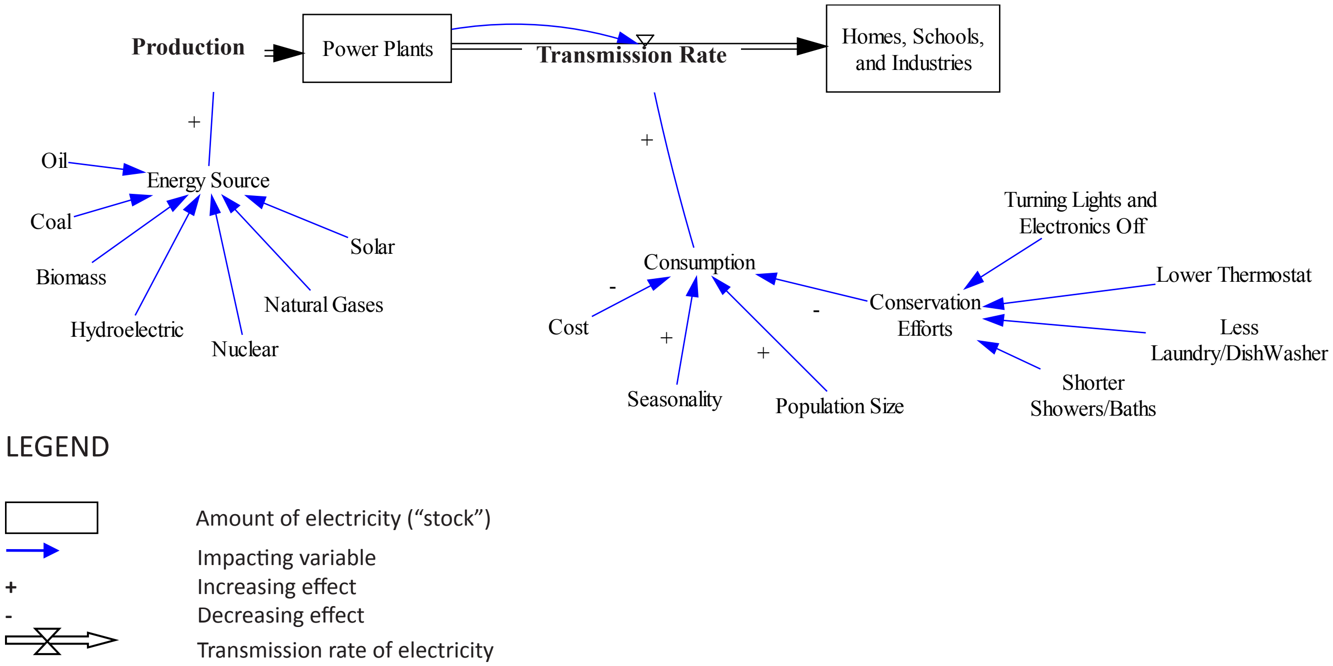


Figure 10. A stock and flow conceptual model examining electricity transmission rates

Mathematical models can vary from simple mathematical formulas to computer simulations. The latter extends the human capacity to examine processes present in systems that are too complex or abstract to work with in a practical manner (e.g., global warming, climate change, rising sea levels, population dynamics of a species, forest stand growth, behaviour of a brake system prototype). Simulations are computer programs that connect various components (variables) of the system using mathematical relationships. They allow the experimenter to explore "what if" scenarios by giving them the flexibility to control certain variables while changing others. This enables greater understanding of complex interactions within the system and how these interactions impact the whole system. When students use computer simulations (e.g., Physics Education Technology - PhET[34]) to explore cause and effect relationships based on gas laws, or circuit electricity, they are practising science by using models. Students should be made aware, however, that because models are oversimplifications of real life, they have limited predictive powers.

Foundations of Scientific Literacy: Content Knowledge

What have scientists learned?

There are many fields of science (e.g., chemistry, physics, biology, geology), each of which is associated with specific theories (explanations), models, concepts, and principles. In science education, multiple fields are often grouped under the categories of life science, physical science, and Earth and space science.

Life Science

Life science examines the growth and interactions of life forms within their environments in ways that reflect their uniqueness, diversity, genetic continuity, and changing nature. Life science includes fields of study such as ecology, zoology, botany, cell biology, genetic engineering, and biotechnology.

Physical Science

Physical science, which encompasses chemistry and physics, is concerned with matter, energy, forces, and the relationships between them. Momentum, change, and the conservation laws of mass and energy are addressed by physical science.

Earth and Space Science

Earth and space science bring global and universal perspectives to students' knowledge. Earth, our home planet, exhibits form, structure, and patterns of change, as does our surrounding solar system and the physical universe beyond it. Earth and space science includes fields of study such as geology, meteorology, and astronomy.

Interdisciplinary Concepts

Interdisciplinary Science Concepts

Matter
Patterns in form and function
Energy and forces
Cause and effect
Equilibrium, stability, and change within systems

In addition to the knowledge generated by specific fields of science, there are a number of *interdisciplinary concepts* that are common to all sciences. For the purpose of this document, these concepts are grouped into five categories: matter; patterns in form and function; energy and forces; cause and effect; and equilibrium, stability, and change within systems. Many of these concepts are not the exclusive domain of science but are also found in mathematics, technology, business, government and politics, education, and law. These themes are fundamental to the conceptual understanding of science and facilitate integrated and higher order thinking by providing a common framework on which students can organize and scientific knowledge. At every opportunity, these concepts should be taught explicitly within the context of the science topic being studied. Only after accumulating a wealth of examples, illustrations, and experiences will students integrate knowledge related to these abstract concepts into their thinking and synthesize their understanding of science. A summary of the more important aspects of each of five interdisciplinary concepts follows.

Matter

The identification, examination, transformation, and cycling of matter within and between systems is of interest to all scientific disciplines. Broad foundational concepts relating to matter include the following:

- All living and non-living entities on the Earth are composed of matter, which has mass and occupies space.
- The smallest unit of matter is the atom.
- Earth's matter is of a finite quantity.
- All matter–including that of plants, animals, elements, and compounds–is formed from various arrangements of atoms; principles that apply to the structure of matter in the physical (inorganic) world also apply to the organic world.
- Atoms are rearranged but not destroyed during chemical change; mass is conserved during chemical change.
- The smallest unit of living matter is the cell; all cells arise from other cells.
- Living matter or "life" is characterized by homeostasis (i.e., regulation of an internal environment), and the ability to metabolize, (i.e., produce energy from chemical reactions), move, grow, reproduce, respond to stimuli, and adapt to the external environment.

Patterns in Form and Function

Form refers to the physical structure, the shape, size, and composition of living and non-living things. Interdisciplinary concepts relating to form and function include the following:

- There is a vast array of living and non-living forms of matter.
- Science classifies matter on the basis of similarities and differences in form (structure) and function.
- There are clear relationships between structure and function in the components of natural and human-made systems. (For example, metallic elements contain atoms arranged in a manner that imparts properties such as conductivity and malleability; anatomical structures such as hollow bones in bird wings support flight.)

Energy and Forces

Energy, the ability to do work, is a central concept of science because all physical phenomena and interactions involve energy. Physics describes the interaction of matter and energy at the universal, macroscopic, and atomic levels and uses mathematical models such as the Newton's laws and Einstein's theory of special relativity to explain some of these interactions. Physics is concerned with concepts such as the conservation of energy and its transformation into various forms, motion, and forces. Chemistry focusses on the amount of energy required for chemical reactions to occur and the resulting energy released or absorbed from the surroundings during those reactions (e.g., combustion of fuels). In the life sciences, the flow of energy through individuals and ecosystems controls, maintains, and drives diverse phenomena such as photosynthesis, growth, metabolism, and interactions within food chains. Fundamental concepts relating to energy and forces include the following:

- The sun is the source of radiant energy for the Earth.
- Energy, like matter, can be transferred or transformed, but never created nor destroyed.
- All matter contains energy as a result of its motion (kinetic energy), position (potential energy), or atomic makeup.
- Forces can be thought of as a push or pull that holds matter together and enables it to change its position, shape, or motion.
- Forces are either contact forces (e.g., collision, friction, tension [applied and spring]) or non-contact forces (i.e., weak and strong nuclear forces, electrostatic and magnetic forces, and gravitational forces).

Cause and Effect
Cause and effect has been more thoroughly addressed on pp. 18–19. Fundamental concepts relating to cause and effect include the following:

- In causal relationships between variables, one variable results in the response or occurrence of another in a consistent manner.
- A major focus of science is identifying, describing, and explaining cause and effect relationships. When possible, these relationships are described mathematically.
- Causal relationships can be complex, such as is seen with chain reactions, biofeedback mechanisms, and biosphere matter cycles.
- Understanding cause and effect helps scientists to predict.
- Correlation does not imply causation.

Equilibrium, Stability, and Change within Systems
A system is an abstract concept that is used in science to describe the part of the universe that is the focus of study. The interaction of components within a system is of interest to all sciences (pp.20–21). Fundamental concepts relating to systems include the following:

- A system is a collection of components that interact with one another so that the overall effect is much greater than that of the individual components.
- The boundaries of a system are determined by the observer and vary in scale (i.e., atomic, microscopic, macroscopic, and universal).
- Within living and non-living systems, dynamic (causal) relationships occur that involve changes in matter and energy.
- A system in which all processes of change appear to have stopped, or which displays constancy or stability is in a state known as equilibrium. When at equilibrium, opposing forces or processes balance in a static or dynamic way.
- Systems move towards equilibrium, a state of stability or balance (i.e., lowest potential energy).
- A cause, such as an outside force or an exchange of energy/matter with the surroundings, will cause a stable system to shift away from equilibrium and to exhibit change.
- Change in systems can occur as a steady trend, in a cyclical fashion, irregularly, or in any combination of these patterns.
- It is the rate of change that is often of most interest to scientists, since the rate of change can have a greater impact than the change itself on the stability of a system.
- Scientists use models as tools that facilitate the understanding and testing of relationships between variables in systems.

Foundations of Scientific Literacy: Decisions and Perspectives

How can science be applied to solve problems?

Science investigates the natural world to develop theories that explain how it works, and laws that describe its patterns of behaviour. Science is not focused on practical outcomes. Instead, technology and engineering apply scientific understanding to propose solutions to human needs or desires. Technology and engineering, like science, are creative human activities with a long history in all cultures of the world. While the three disciplines differ in purpose and methodologies, they are inextricably linked.

The needs addressed by the application of science often arise from humans adapting to and/or modifying their environment. The solutions include new products, processes, systems, or structures. For example, the application of science in agriculture addresses the need to feed an exploding population by developing new equipment, fertilizers, crops, animal breeds, and computer technologies that automate tasks such as feeding and milking. Mechanical, electrical, and civil engineering facilitate humans to dam and divert water in quantities that enable large-scale irrigation and the production of hydroelectric power. The application of science in medicine has resulted in technologies that detect disease in the early stages; new processes that can repair, replace, and rebuild parts of the human body; medicines that combat pathogens and regulate body functions; and bioengineering techniques that allow us to modify genes and grow new organs in alternative species.

What are the considerations when applying science?

Science is <u>not</u> a matter of opinion. However, decisions regarding how we should apply science, or act upon what we have learned, are based upon opinions that are influenced by various personal, political, cultural, ethical, and economical perspectives. For example, science has resulted in our understanding of chemical and biological principles that enabled the development of pesticides, tools to reduce disease and improve crop yields. However, opinion differs regarding which pesticides to use, when to use them, and in what quantity they should be used. To complicate things further, perspectives shift as our understanding progresses. A case in point is the story of the synthetic pesticide DDT that was developed in the 1940s to combat insect-borne diseases such as malaria. As evidence mounted about this chemical's severe adverse effects on the environment, and predatory birds in particular, there was a call to ban DDT in most countries and to use other pesticides more judiciously.

Decisions that we are required to make vary from personal day-to-day decisions to complex ethical issues that can affect entire species, including our own. As individuals, we make daily choices regarding food, health, and energy, often basing them upon scientific understanding. For example, studies on climate change have created a greater awareness that the burning of fossil fuels (e.g., coal, oil, gasoline) has caused an increase in atmospheric carbon dioxide, which has in turn resulted in climate change. This information has inspired many to consider alternative ways to heat their homes and travel to work. As consumers, our decisions have influenced research and the development of new technologies such as solar panels, windmills, and geothermal heating. As citizens in a democracy, we can influence the development and acceptance of policies, such as the United Nations Kyoto Protocol. Decisions at this level can affect the entire planet.

As science continues to open doors for innovation and the development of new technologies, we will continue to be called upon to make difficult decisions that require weighing the risks and benefits of these advancements. It is important that we teach our students how to think ethically about the application of science and technology and to consider the question, "Just because we can, should we?" Human ingenuity is frequently accompanied by impacts that can reach far around the globe and long into the future. Therefore, it is imperative for both sustainability and global harmony that we develop scientifically literate, ethical, and critical thinkers who are capable of deciding upon reasonable courses of action, while considering many varying perspectives. This requires that students have the opportunity to practise flexible thinking, listening to others, questioning, reasoning, and synthesizing their understanding.

Components of Scientific Inquiry

The process of developing scientific knowledge is a complex interplay of experimentation; current knowledge; modification of theories; debate; social, cultural, political, and economic influences; and peer review and acceptance. This observation of science has often resulted in the declaration, "There is no one scientific method." This statement is true in the sense that there are many ways to inquire or answer scientific questions, but it has seemingly resulted in a misconception in science education that the approach to scientific investigation is vague and that there are no common elements in the way that scientists inquire. While *study designs* (p.19) vary depending on the question being asked, the *process* of developing new scientific knowledge always involves a number of aspects or stages (Figure 11). These aspects include asking testable questions about the natural world, collecting and analyzing evidence to answer those questions in a logical manner, and sharing that knowledge with other experts so that it can be skeptically reviewed and validated by other lines of evidence. Each stage of scientific inquiry is associated with specific skills and competencies (Table 4).

Stages of Scientific Inquiry

Initiating and planning
Performing and recording
Analyzing and interpreting data
Communicating findings

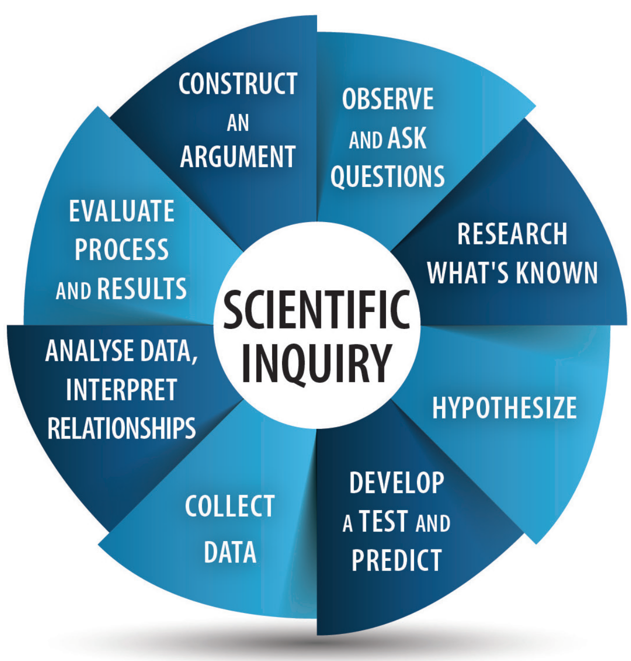


Figure 11. Components of the scientific/experimental process

Component of Scientific Inquiry (learning emphasis)		Skills and Competencies
Initiating and Planning (creativity and innovation)	Exploring, tinkering, and asking questions	• observing • activating prior knowledge • brainstorming • researching for background information
	Hypothesizing	• selecting and refining questions or hypotheses • inferring (inductive reasoning), predicting
	Designing and investigating	• planning (time, materials, sequence) • identifying variables (independent, dependent, and ones to be controlled) • identifying data to be collected that will help answer the question • adapting or developing a procedure • performing a trial run
Performing and Recording (manipulative skills and problem-solving)	Performing an investigation and collecting evidence	• using equipment and techniques safely or running computer simulations • building prototypes, developing models • following instructions and sequencing tasks • reading digital and analog scales • recording quantitative and qualitative data • measuring accurately, recording precision of measurement • managing time, evaluating progress, problem-solving as necessary • collaborating
Analyzing and Interpreting Data (higher order/ critical thinking)	Analyzing and interpreting evidence	• analyzing patterns and trends • using mathematical processes, knowledge, and skills • graphing • transforming representations (e.g., graphs $\leftrightarrow$ tables, diagrams $\leftrightarrow$ text) • comparing and contrasting • classifying • identifying cause and effect, or correlational relationships • making conclusions
	Evaluating errors	• evaluating scientific errors (degree of reliability and certainty of measurement, and control of variables) • reflecting on ways to improve future investigations and data
Communicating Findings (synthesizing, reasoning, argumentation)	Defending and communicating findings	• constructing explanations • using writing, media, visual literacy, and technology skills to create a product that communicates findings/makes a claim • explaining (discussing) results • using deductive reasoning, evidence, and argumentation to defend claim (accept or reject a hypothesis)
	Proposing further questions	• identifying new questions that arise from the investigation

Table 4. Stages of the scientific inquiry process and selected skills

STEAM Problem-Solving Processes

The acronym STEAM represents Science, Technology, Engineering, Art, and Math. STEAM education is a pedagogical approach that provides students with the opportunity to integrate learning associated with these five disciplines while solving meaningful problems. The original acronym STEM was introduced in the 1990s by the National Science Foundation. The “A” was added to STEM in recognition that **creative thinking** normally associated with art is as necessary as **analytical thinking** when solving problems in science, engineering, and technology. The ability to think mathematically is also an integral aspect of these three fields.

Selected Habits of Mind and Skills Encouraged by STEAM

- creativity
- innovation
- persistence
- resilience
- flexibility
- collaboration
- communication
- critical thinking
- analytical thinking
- manipulative skills
- digital fluency

Problem-solving is an iterative, multi-layered, and multi-stepped process that requires flexible thinking patterns (Figure 12). The analytical thinking component involves selecting, gathering, sorting, comparing, and contrasting information. Analytical thinking is *convergent thinking*, which helps to identify and narrow possible solutions. Creative thinking is required to solve broad, open-ended problems that do not have a readily apparent solution and are not single-outcome specific. Creative processes involve *divergent thinking* or out-of-the-box thinking. A creative thinker may consider solutions that are based on intuition and emotion rather than logic. Creative solutions can also arise from observation, inspiration, and serendipity. STEAM activities are designed to encourage the flexibility to move back and forth between these two cognitive processes. They also support the development of other habits of mind necessary for STEAM, such as persistence and resilience.

All five disciplines do not have to be targeted at the same time during a STEAM activity. To obtain the benefit of STEAM-based instruction, the problem presented should not have a readily apparent solution or be single-outcome specific. The problem should be open-ended and designed in a way that the learner has more than one possible path to the solution. *Productive struggle* and reflection should be encouraged.

Problem-Solving Component	S	T	E	A	M
	Science	***Technology***	***Engineering***	***Art***	***Mathematics***
Nature of Problem	Extending our understanding of the natural world	Developing ways to extend human capacity	Addressing a human need or concern	Expressing and interpreting human perception	Discovering mathematical relationships
Name of Process	Scientific inquiry	Technology design	Engineering design	Creative process	Mathematical analysis
Initial Question	What causes...?	How can I ...?	How can I make...?	Imagine if...	What is the relationship...?
Solutions and Products	Communications of new knowledge	Digital products, digital processes	Structures, equipment, machines, processes	Aesthetic expression, products, processes	Numerical solutions, equations

Table 5. STEAM problem-solving

STEAM problem-solving processes (i.e., scientific inquiry, technology and engineering design, the creative process, and mathematical analysis) differ in the nature of the question and the solution or product. However, all are based on the generic problem-solving process (Figure 12). All are iterative processes that involve reflection, evaluation, and feedback throughout. All require analytical thinking and creative thinking. Figure 13 compares the problem-solving processes for science, engineering, art, and math.

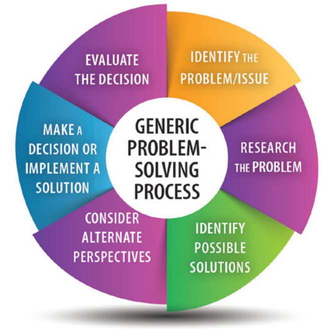
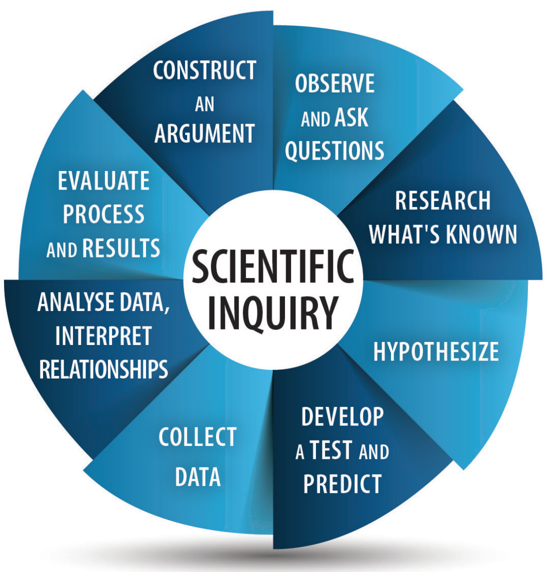
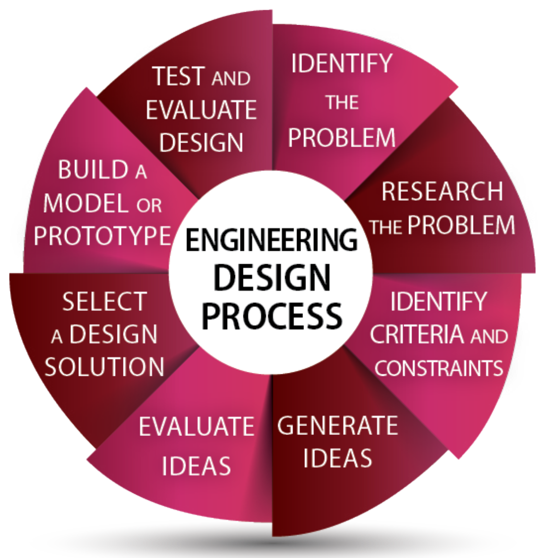


Figure 12. The generic problem-solving process





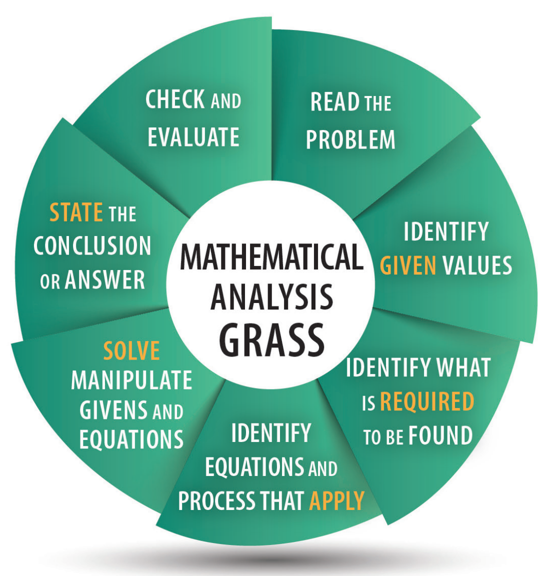


Figure 13. A comparison of STEAM problem-solving processes

Interdisciplinary Skills

In addition to problem-solving, a number of interdisciplinary skills are required in science.

Mathematical Skills

Mathematics can be considered to be the language of many sciences. Mathematics is used to describe relationships, enable predictions, quantify, and validate evidence. Science provides a concrete context in which students can develop skills such as mental mathematics and estimation, problem-solving, mathematical reasoning, visualization, and connecting mathematical ideas to the real world. During Grades 7-10 mathematical skills used in science include, but are not limited to

- measuring and applying appropriate units for quantities such as length, mass, and volume;
- performing unit conversions;
- solving problems using equations;
- expressing patterns and relationships mathematically;
- determining totals, averages, percentages, ratios, and proportions;
- presenting and interpreting data in graphical and tabular form;
- visualizing space and shape from different perspectives.

Technology Skills

Technology is concerned with developing innovative solutions to problems arising from humans adapting to their environment. Science and technology have been inextricably linked throughout history. Technology is constantly producing new developments that have potential use in science and lead to a greater understanding of our world. New scientific developments, in turn, can inspire further technological innovations.

EGC Technological Fluency: Students are expected to use and apply technology to collaborate, communicate, create, innovate, learn, and solve problems.

Technologies used in science include tools and equipment (e.g., thermometers, microscopes) common to science investigations and data gathering, as well as communication and information technologies. Students should develop skills specific to both forms of technology.

1. Manipulative Skills

Manipulative skills are those skills involved with the handling of equipment and material. Developing confidence in using equipment, materials, and techniques enables students to explore and inquire in a safe manner while focusing on the concept being investigated rather than "how to." These skills take time to develop and require that students in Grades 7 to 12 be given frequent opportunities to independently use lab equipment in a risk-free atmosphere. During the intermediate years, students should develop proficiency in skills and dexterity required when

- making accurate measurements (e.g., length, mass, volume, time, temperature);
- using instruments (e.g., thermometers, multimeters);
- selecting and using appropriate glassware for measuring and mixing;
- using and caring for instruments, including knowing their use, parts, and adjustments (if applicable);
- employing safe practices when using chemicals and equipment;
- connecting components, constructing simple apparatuses, and creating simple innovations.

Communication and information technologies (CITs) can be used during all steps of the science inquiry process.

2. Data Collection and Analysis
    - Data loggers (e.g., temperature probes, motion detectors) permit students to collect and analyze data in real time.
    - Spreadsheets and graphing software can facilitate the analysis and display of student-collected data or data obtained from databases.

3. Visualization and Imaging
    - Simulation/modelling software provides opportunities to create and/or use models to explore concepts that are difficult to visualize, and perform experiments that are unsafe or difficult to perform in the classroom.
    - Students may collect their own digital images and video recordings for analysis, or they may access digital images and online video software to help enhance understanding of scientific concepts.

4. Communication and Collaboration
    - In addition to the usual tools involved in accessing information, and creating reports and presentations, the Internet can be a means of networking with scientists, teachers, and other students through social media, cloud computing, blogs, and video-conferencing to collect and share information, and work on projects collaboratively.

Language Skills

Language is the principal means through which students communicate with others and make meaning of scientific concepts, phenomena, and claims. These skills can be classified in terms of the input and output of information.

The input of information is addressed through reading, listening, and viewing. Learning about scientific concepts, claims, and ideas involves comprehending specialized vocabulary and understanding how to interpret informational texts such as textbooks, magazine articles, lab instructions, and case studies and their features (graphs, charts, tables, and diagrams). Comprehending the intent and purpose of text when evaluating the scientific validity of claims requires the ability to interpret tone and bias, and to determine the logic of arguments.

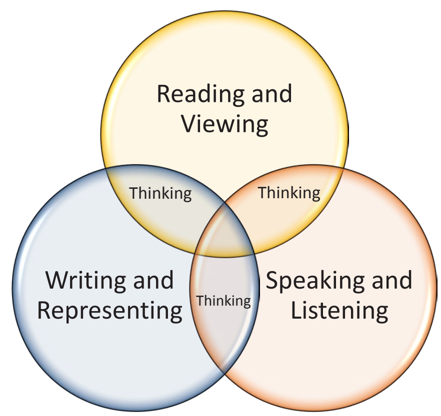


Figure 14. The nature of language arts adapted from *Atlantic Language Arts* Grade 7–9 (2010)

The output of information involves communication by speaking, writing, and representing. The purpose of scientific writing is to communicate new findings so that they can be retested, validated, and expanded upon by other scientists in the global scientific community. The style of writing employed by scientists works to this purpose by being succinct and precise, and by avoiding descriptive and colloquial words that may create bias or not be universally understood. Nomenclature rules (i.e., naming rules) for organisms and chemicals are determined by organizations such as IUPAC (International Union of Pure and Applied Chemistry) and the ICZN (International Commission on Zoological Nomenclature). When students write scientifically, they not only construct new understanding of the scientific concept being examined, but they also practise the basic principles inherent to the nature of science.

Instructional Strategies

Children arrive in the school system with a natural curiosity and an interest in investigating and exploring the world about them. They use reasoning based on their experiences as they try to understand how things work. This innate curiosity and interest can be can be encouraged through a well-balanced science program when students are provided with opportunities to explore, talk, think, write, read, visualize, apply, and design.

> "A rich science education has the potential to capture students' sense of wonder about the world and to spark their desire to continue learning about science throughout their lives." —NRC

Teaching is both a science and an art. There is a wealth of instructional strategies described in the literature that teachers have at their disposal when creating a learning environment that best suits the needs of their students. Figure 16 depicts strategies specific to literacy and numeracy development, as well as those that can be classified within four broad categories of instruction: community-based learning, direct instruction, indirect instruction, and interactive instruction.

- *Community-based Learning* is learner-centered and activity-oriented; builds connections to the community through real-life experiences; emphasizes the process of learning rather than the product; purposefully fosters the development of individual student initiative, self-reliance, and self-improvement; includes learning in partnership with another individual or as part of a small group; and offers flexible and varied learning opportunities.
- *Direct Instruction* is highly teacher-directed; effective for providing information or explicit teaching; and is useful when developing step-by-step skills, introducing other teaching methods, or actively involving students in knowledge construction.
- *Indirect Instruction* is mainly learner-centered and complements direct instruction; and it involves learning concepts through the contexts of inquiry, induction, problem-solving, decision making, and discovery.
- *Interactive Instruction* relies heavily on discussion and sharing among learners; allows for a range of groupings and interactive methods; and includes total class discussions, small group discussions, or students working collaboratively on projects.

The gradual release of responsibility for learning is an instructional strategy commonly used to teach process skills. It begins with the teacher modeling the process and then purposefully scaffolding learning in a manner to move the student towards greater independence. In the science classroom, this strategy is powerful when teaching complex processes such as problem-solving, experimental design, and written argumentation.

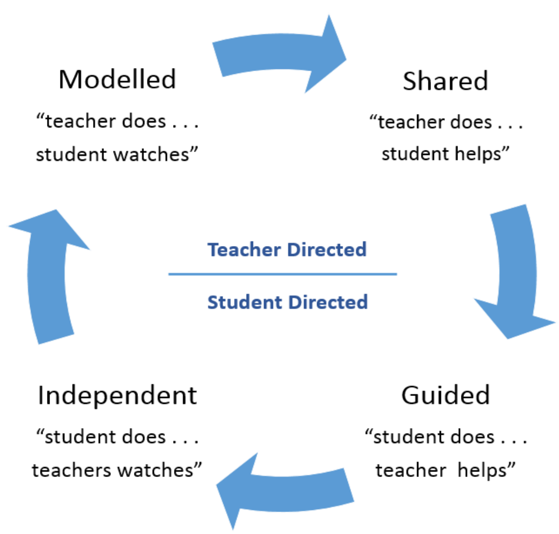


Figure 15. Gradual release of responsibility for learning

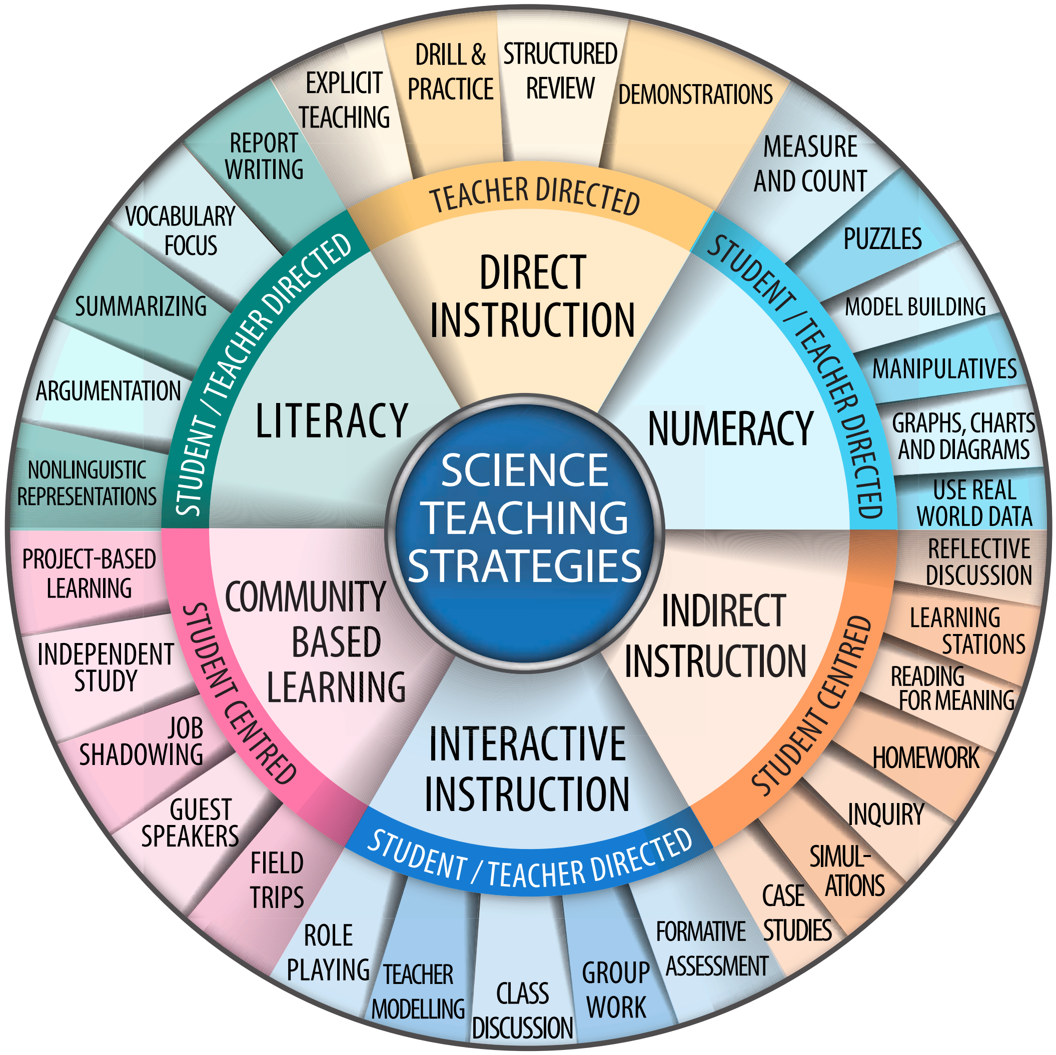


Figure 16. Science instructional strategies. Additional strategies relating to literacy can be found in Appendix D, p. 89.

Assessment and Evaluation

Assessment and evaluation are integral components of the teaching and learning process. They are continuous activities that are planned for and derived from specific curriculum outcomes (SCOs) and should be consistent with instruction. Effectively planned assessment and evaluation improves and guides future instruction. It also promotes learning, builds confidence, and develops students' understanding of themselves as learners.

Students should know what they are expected to learn as designated by SCOs and the criteria that will be used to determine the quality of their achievement.

Assessment must provide opportunities for students to reflect on their progress, evaluate their learning, and set goals for future learning.

Assessment is the process of gathering evidence about student learning. Assessments need to be reflective of the cognitive process and type of knowledge indicated by the SCO (pp. 8–9). The achievement indicators inform teachers of the depth and breadth of skills, knowledge, and understandings expected for each SCO.

Assessment has three interrelated purposes:

- assessment *for* learning to guide and inform instruction (formative)
- assessment *as* learning to involve students in self-assessment and setting goals for their own learning (formative)
- assessment *of* learning to determine student progress relative to curriculum outcomes (summative)

Triangulation is a process by which a teacher uses evidence about student learning from three different sources. These sources include conversations, observations, and products. Collecting data from a balance of these sources ensures reliable and valid assessment of student learning.

Evaluation involves analyzing and reflecting upon various forms of evidence of student learning and making judgments or decisions regarding student learning based upon that evidence.

Effective assessment strategies

- must be valid in that they measure what is intended to be measured and are reliable in that they consistently achieve the same results when used again, or similar results with a similar group of students;
- are appropriate for the purpose of instruction and learning strategies used;
- are explicit and communicate to students and parents the expectations and criteria used to determine the level of achievement;
- are comprehensive and enable all students to have diverse and multiple opportunities to demonstrate their learning consistently, independently, and in a range of contexts in everyday instruction;
- accommodate the diverse learning needs and experiences of the students;
- allow for relevant, descriptive, and supportive feedback that gives students clear directions for improvement, and engages students in metacognitive self-assessment and goal setting that can increase their success as learners;
- assist teachers in selecting appropriate instruction and intervention strategies to promote the gradual release of responsibility of learning.

Considerations for Instruction

The following table provides examples of assessment strategies that can be used in science. The type of assessment should be selected purposefully to ensure that it matches the specific curricular outcome(s) describing what students are expected to know and do. Teachers should also consider the variation of assessments used and the assessment interval.

SCIENCE ASSESSMENT STRATEGIES			
Self/Peer Assessment	**Skills/Performance**	**Observations/ Conversations**	**Pencil/Paper**
Formative	**Summative**	**Summative/Formative**	**Summative**
• written practice questions • science journal • learning reflections • homework • formative quizzes • descriptive feedback • exit slips	• debates/arguments • presentations • safe lab practices • lab skills • collaborative group work • applying experimental and engineering design processes	• planned observations (formal) • unplanned observations (informal) • small group discussion • interactive questioning • student-teacher conference • anecdotal records	• portfolio • science notebook • lab report • case study analysis • experimental design analysis • tests • artifacts with reflections • models, drawing, charts, tables, and graphs • research paper • written argument • assignments

Prince Edward Island
CANADA

Education, Early Learning and Culture
English Programs

Prince Edward Island Science Curriculum

Science

Grade 9

Curriculum Outcomes

CURRICULUM

17ED10-46561

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Implementation September 2018

Grade 9 Science Overview

During Grades 7–10, students will transition from early exploratory phases of scientific literacy and begin to approach scientific inquiry and critical thinking more systematically (Appendix B, pp. 86–87). This development of scientific literacy is a function of the kinds of tasks and the discourse in which students participate. A hands-on, minds-on approach will engage students and can encourage a lifelong interest in science. At the same time, it will encourage learners to recognize that science is not only a body of knowledge but a process of understanding and reasoning. Competencies such as critical thinking and citizenship will be fostered when students examine controversial and real-world issues such as pseudoscience, biodiversity, sustainability, climate change, over-population, and clean energy.

In this curriculum guide, the specific curriculum outcomes are not arranged according to textbook units. This design is used to shift the focus away from a primary emphasis upon science topics or content, towards scientific literacy as defined by the four identified foundations: Nature of Science, Procedural Knowledge, Content Knowledge, and Decisions and Perspectives (Table 6, p. 38). Sixteen specific curriculum outcomes (SCOs) within these four foundations are used to identify the skills, knowledge, and understandings that students are expected to develop and/or deepen. Seven questions that are intricately linked to these outcomes should be interwoven within instructional activities throughout the year:

- What is science?
- What is not science?
- What does doing science look like?
- What have we learned from science?
- How can we apply science to solve human problems?
- What should we consider before we apply science to solve problems?
- How does science relate to me today and in the future?

Traditional "content" in science education consists of the scientific explanations (theories) regarding concepts such as structure, function, change, and causal relationships that the process of science has revealed. Content remains an integral part of this course but is viewed as the context through which "science" is learned. The three topics identified as context for Grade 9 are Biodiversity and Sustainability of Ecosystems (life science), Patterns in Atoms, Elements, and Compounds (physical science —chemistry), and Understanding Electricity (physical science —physics). To demonstrate their understanding of these topics, students are expected to not only state and recall facts, but to apply their understanding to solve and analyze contextualized problems. They should also be able to make connections between the specific details of what they are learning to the interdisciplinary concepts (pp. 22–24) and enduring understandings described on the introductory page for each set of SCOs (e.g., p. 40). Teachers may elect to use learning experiences outside of these topics, such as science fair projects, to help students achieve outcomes related to skills and processes (e.g., SCO PK 3 and/or SCO PK 4, experimental and engineering design).

An online curriculum supplement provides suggested pacing and instructional strategies that can help teachers with the planning of this course. A list of authorized resources can be found in Appendix A, p. 85.

Foundation /GCO	Specific Curriculum Outcome and Code		Cognitive Process
Nature of Science	NoS 1	Understand science as a unique way of knowing.	Understanding
	NoS 2	Evaluate, with support, if a reported idea or claim is scientifically reasonable.	Evaluating
Procedural Knowledge	PK 1	Construct meaning from science-based informational text.	Applying
	PK 2	Compose written reports and arguments to effectively communicate scientific thinking.	Creating
	PK 3	Design an investigation to examine a relationship between variables.	Creating
	PK 4	Apply the engineering design process to develop a technical solution that addresses a need.	Applying
	PK 5	Conduct investigations safely to collect data that can be used to answer questions or learn scientific concepts.	Applying
	PK 6	Analyze data to determine patterns, trends, and causal relationships.	Analyzing
	PK 7	Evaluate, with support, the strength of evidence resulting from a scientific investigation.	Evaluating
Content Knowledge	CK 1	Analyze causal relationships between sustainability of life, biodiversity, population size, and cycling of matter and energy.	Analyzing
	CK 2.1	Examine patterns in the structure and properties of atoms and their elements.	Analyzing
	CK 2.2	Examine patterns in the composition of ionic and molecular compounds.	Analyzing
	CK 3	Investigate to develop understanding of the principles of electricity.	Analyzing
Decisions and Perspectives	DP 1	Examine the benefits and risks of scientific and technological developments.	Analyzing
	DP 2	Defend decisions or judgments regarding scientific or technological issues, with consideration of multiple perspectives.	Evaluating
	DP 3	Reflect on personal characteristics, skills, and opportunities that connect to a career in science.	Evaluating

Table 6. Grade 9 Science specific curriculum outcomes

Table of Specifications (ToS)

A table of specifications (ToS) is a two-way table that describes the relative weighting of each unit or cluster of outcomes within a scientific literacy foundation. The ToS also provides the relative weighting of summative assessment levels within a course (see Appendix E, p. 90 for a description of Levels 1–3). While the primary purpose of a ToS is to designate the cognitive demands for summative assessments, it can also be used to provide insight when planning instruction and other forms of assessment.

Foundation/ GCO	Level 1	Level 2	Level 3	Weight
Nature of Science	NoS 1			**10%**
			NoS 2	
Procedural Knowledge		PK 1		**40%**
			PK 2	
			PK 3	
		PK 4		
		PK 5		
		PK 6	PK 6	
			PK 7	
Content Knowledge	CK 1	CK 1		**40%**
	CK 2.1	CK 2.1		
	CK 2.2	CK 2.2		
	CK 3	CK 3		
Decisions and Perspectives		DP 1		**10%**
			DP 2	
			DP 3	
Weight/Level	**24%**	**43%**	**33%**	**100%**

Table 7. Grade 9 Science table of specifications (ToS)

Nature of Science

NoS: Students will comprehend science as a way of knowing about the natural world that uses valid, empirical evidence and logical reasoning. They will recognize that scientific knowledge is dynamic and probabilistic in its nature, evolving as new evidence and ideas are presented, and accepted by a community of scientists only after rigorous review.

	Specific Curriculum Outcomes	Cognitive Process
NoS 1	Understand science as a unique way of knowing.	Understanding
NoS 2	Evaluate, with support, if a reported idea or claim is scientifically reasonable.	Evaluating

Enduring Understandings
Students will understand that
- ❖ Science is a specific way of knowing that involves a process of questioning, predicting, testing (analyzing and interpreting data), and developing reasoned arguments.
- ❖ They should be skeptical and think critically about scientific claims before accepting them.
- ❖ There are consequences to accepting and making decisions based on false claims.

Critical Thinking Prompts
- ❖ What would our world look like if science did not exist?
- ❖ Why do people claim that their ideas are scientific when they are not?
- ❖ Who should be responsible for making sure ideas reported on the news or social media are accurate?
- ❖ What is the responsibility of citizens regarding pseudoscience?

Introduction

Two specific curricular outcomes address the scientific literacy foundation Nature of Science, which is described in detail on pp. 15–17.

Specific curriculum outcome NoS 1 is concerned with the underlying principles and characteristics of science as a way of learning about the natural world. Students will come to understand that science is more than a body of facts; it is also a way of thinking that involves specific processes and logical reasoning. To meet SCO NoS 2, students are expected to apply this understanding and use critical thinking skills to evaluate whether or not a claim or "statement of truth" is scientifically reasonable. The claims to be examined include those that can be classified as *pseudoscience,* as well as ones that are the result of poor and/or fraudulent science. Pseudosciences do not follow scientific principles (e.g., testing hypothesis, requiring repeatable results). Claims of this nature are most often made by individuals outside of the science community and found in social and mass media. Poor and fraudulent science claims are those made by individuals within the scientific community who do not follow the rules of science (e.g., they present data that is falsified, exaggerated, or biased). Fraudulent implies intent. While this is not the norm for most scientific research, it is an important consideration when teaching students the rationale behind aspects such as experimental design, collecting, analyzing and evaluating data, and peer review. The end purpose of these outcomes is to encourage students to become skeptical thinkers and develop many habits of mind necessary for scientific and digital literacy.

The table below provides links between the Nature of Science specific curriculum outcomes and other subject areas. This information is to help teachers build upon students' previous learning and see potential opportunities for integrating science with other areas.

SCI 9 SCO	Course	Related Specific Curriculum Outcomes	
NoS 2	9 ENG	SCO 1	Justify a point of view using effective communication.
		SCO 2	Use a wide range of communication strategies and skills effectively in formal and informal situations.
		SCO 4	Evaluate purpose, structure, and characteristics of a variety of texts (fiction and non-fiction, drama, poetry, visual, multimedia, and research).
		SCO 7	Use properly cited information from multiple sources to support points of view.

NoS 1		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

Nature of Science

NoS 1 Understand science as a unique way of knowing.

Achievement Indicators

Students who have achieved this outcome should be able to

a. describe science as both the *body of knowledge* concerned with explanations about the natural world, and the *processes* that are used to develop this knowledge;

b. recognize that people of all genders, societies, cultures, and ethnicities use and contribute to science;

c. recognize that there are different ways we “know” (e.g., by authority, emotion, experience, faith, intuition, memory, indigenous way of knowing, and scientific reasoning);

d. identify concepts that are the focus of scientific studies (e.g., climate change, sustainability of ecosystems, fluids, heat, electricity, light) and those that are not (e.g., astrology, magic, reading the future, ghosts);

e. identify questions (i.e., descriptive and causal) that can be answered by science and those that cannot (e.g., ethical, those pertaining to value);

f. identify characteristic features of the scientific process (scientific way of knowing) including
   - asking questions, making observations and proposing hypotheses (tentative explanations for cause and effect questions),
   - testing hypotheses and predicting outcomes of a test (deductive reasoning),
   - collecting, analyzing, and evaluating data (i.e., building evidence),
   - using analyzed data to support or refute hypotheses (argumentation),
   - sharing new findings for skeptical review and discussion within the scientific community,
   - using findings to develop and revise explanations (i.e., theories), models, and laws;

g. contrast the use of the words *theory*, *fact*, *hypothesis*, and *law* in science and common language;

h. use illustration, analogies, or models to convey the complexity and iterative nature of developing scientific knowledge.

Guiding Questions

❖ What does “knowing something scientifically” mean? What are other ways we “know”?
❖ What sorts of things do scientists study? What sorts of things are not studied by scientists?
❖ What kind of questions are asked in science?
❖ How does the meaning of the words *theory, fact,* and *law* differ in science and everyday language?
❖ How is the development of scientific knowledge (e.g., theories) like a puzzle?

Citizenship	Communication	Personal-Career Development
Creativity and Innovation	Critical Thinking ✓	Technological Fluency

Elaborations

Specific curriculum outcome NoS 1 encourages students to become aware of the concept of knowledge and how we “know” scientifically. Prompting students early in the year to share their understanding of what they think science is will likely reveal the misconception that science is a collection of isolated facts about different topics. In reality, science is both a body of knowledge about the natural world and a process that involves rational reasoning to develop that knowledge. How well that process is employed is significant to the validity of our knowledge. The concepts addressed by SCO NoS 1 should be reinforced throughout the school year within other contexts such as inquiry activities. This outcome also prepares students for SCO NoS 2, which addresses thoughtful decision-making regarding the scientific validity of claims such as those seen in the media.

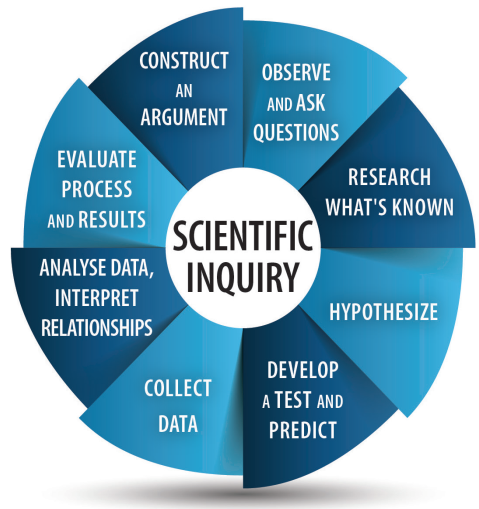


Figure 18. The scientific inquiry process

Diagrams such as Figures 5 (p. 14), 6 (p. 16), and 18 can be used to help students visualize essential aspects of developing scientific knowledge (i.e., the scientific process). Like all models, these diagrams are over-simplifications and do not communicate the complexity or iterative nature of the process by which theories, laws, models, and scientific explanations are developed. Scientific theories are, in actuality, developed over extended periods of time, and often synthesize many hypotheses, laws, principles, and facts from a vast number of studies representing diverse fields (i.e., multiple lines of evidence). They are subject to expert critical review along the way. Students should understand that theories are not passing, tentative suggestions as the term implies in everyday language, but well-substantiated explanations that are accepted until disproved or modified. Theories, like all forms of scientific knowledge, are dynamic; they evolve or suddenly shift as new discoveries are made. These discoveries are often facilitated by new technologies that extend our ability to collect evidence from deeper inside the atom and further out into the universe.

It is important for students to recognize the limits of science. Science can only address questions that are testable and concerned with natural phenomena. These types of questions include descriptive and causal questions. Descriptive questions can be answered by observing and measuring. They include the following: What lives there? What is it composed of? What are its properties? How many? Causal questions are those focussed on cause and effect and are the basis of hypothesis: Why did ...? What caused that to happen? Questions related to supernatural phenomena, morality, value, aesthetics, and ethics cannot be answered by science.

Another limit of science is that it is probabilistic. Science never claims 100% certainty, and it often describes behaviours or relationships in terms of probabilities. This does not mean that science is not reliable or credible; some of the things we know have been tested many times and/or over hundreds of years, and our certainty of some understandings approaches 100%.

For more details on reasoning, theories, laws, limitations of science, and models, see pp. 15–17 and pp. 20–21.

NoS 2		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

Nature of Science

NoS 2 Evaluate, with support, if a reported idea or claim is scientifically reasonable.

Achievement Indicators

Students who have achieved this outcome should be able to

a. use the following vocabulary appropriately: *argument, bias, claim, evidence, opinion, pseudoscience, skeptical;*

b. demonstrate skeptical and critical thinking when presented with a claim supposedly based on science;

c. demonstrate beginning awareness of the difference between inductive and deductive reasoning (i.e., recognize that inferences based on observations are not scientifically reasoned conclusions);

d. rate the publishing medium in terms of reliability (e.g., blogs, Twitter, and Facebook are less reliable than university websites, textbooks, or scientific journals);

e. assess the credibility of the source of the claim (e.g., scientist, corporation, lobbyist, journalist, marketer, politician) by considering their possible intent or bias (e.g., sells the product, funded by or belongs to a partisan group), and identifying any other "red flags" (e.g., inflated sense of expertise, over-confidence, lack of expertise in area);

f. assess if the vocabulary is non-scientific (i.e., flamboyant, exaggerative, vague, colloquial, subjective, or emotive) or overstated (i.e., emphasizes words such as *scientific*, *fact*, *proves*, *truth*, *evidence*);

g. infer if the argument supporting the claim is scientific by considering if, for example, it
  - is based on testing and data that has been verified by others,
  - is supported by multiple lines of evidence,
  - identifies possible sources of bias present when evidence was collected,
  - keeps possible confounding variables that could have affected the conclusion consistent,
  - is reasonable in consideration of well-established scientific "facts";

h. infer if the argument supporting the claim is non-scientific due to its use of testimonials, opinion, personal experience, miraculous claims, conspiracy theories, or results that cannot be repeated by others;

i. conclude, with justification, if a reported idea or claim is scientifically reasonable.

Guiding Questions

❖ What is being claimed? Why is it important to be skeptical about claims that are too good to be true?
❖ Who is making the claim? What is their expertise? What is their possible motive or bias?
❖ Are there clues in the language being used that suggest it is not real science?
❖ What is the evidence being presented?

Citizenship ✓	Communication ✓	Personal-Career Development
Creativity and Innovation	Critical Thinking ✓	Technological Fluency ✓

Elaborations

Critical thinking and skepticism are essential aspects of scientific literacy. Today's youth are bombarded with claims in various media that are based on exaggerations of scientific findings, testimonials, pseudoscience (i.e., beliefs or practices with no scientific basis), conspiracy theories, and false information supposedly supported by science. Some examples include familiar myths such as lightning never strikes twice, natural chemicals are safe, all chemicals in food are toxic; the miraculous wonder of a single food, diet pill, or personal care product; and the conspiracy theory that climate change is a hoax. It is important that intermediate students begin to develop critical thinking skills that can help them discern reasonable scientific claims from fictitious claims supposedly based upon science. They should also be provided with the opportunity to reflect on the consequences of making decisions based on false information, and the responsibility of not propagating such claims.

When evaluating some claims, students may not have sufficient understanding of the science being used as "evidence" to argue for or against a claim. However, there are many indicators that the novice can use to make decisions about the validity of what they are viewing. These include word choices, tone, source, and the type of publishing medium. Students should also be encouraged to apply their understanding of the nature of science (SCO NoS 1). For example, claims related to supernatural phenomena are scientifically unreasonable since the focus of science is the natural world. Claims that cannot be tested or repeated by others also violate the principles of science. Teachers may wish to co-construct a checklist of criteria with students to help guide their thinking.

Is the Claim Scientifically Valid?

- Does it focus on the natural world?
- Was it tested? How valid is the evidence (data)?
- How reliable is the person making the claim?
- How reliable is medium where the claim is being made?
- Are there "red flags" in the language used?
- Does the claim fit in with well-established science?
- What are the possible alternative explanations?
- Is the claim embraced by the scientific community?

Inductive and deductive reasoning are opposites. Inductive reasoning uses observations and experiences to make a broad generalization. For example, if six crows were observed and they were black, inductive reasoning could lead to the conclusion that all crows are black. Inductive reasoning can lead to false conclusions and often support our biases. In science, this form of reasoning can be used to develop hypotheses that must then be tested deductively (see Figure 6, p. 16). Deductive reasoning begins with a generalization or hypothesis, which is tested to see if it is observed in specific situations. One way to test the claim that all crows are black would be to sample populations of crows and determine the probability of a crow being black. While the probability would be high, detecting a small percentage of albino crows would prove the original claim that "all crows are black" to be false. Science involves an interplay of inductive and deductive reasoning. However, conclusions based on observations (inductive) that have not been tested (deductive) do not reflect scientific thinking and can be considered as "jumping to conclusions." Scientific reasoning requires testing.

In addition to claims that take place outside of the scientific community, some claims made inside the community are not scientifically valid. Science is guided by an ethical code that includes honest reporting of the methodologies used, appropriate sample sizes, and results accompanied by known scientific errors. The majority of scientists have integrity and protect the validity of science. However, there are some very famous cases of scientific fraud that have occurred when individuals violated the scientific code (e.g., Robert A. Millikan's experiment measuring the charge of an electron, Cyril Burt's study on limitability of intelligence, Wakefield's report on vaccines causing autism). The requirements for reproducibility and a critical review process help science to be self-correcting, but they are not without issues. Amendments sometimes occur after the damage has been done. The credibility of science depends on honesty and integrity. Providing students with the opportunity to examine historical cases can encourage them to apply this understanding to their own work.

Procedural Knowledge

PK: Students will understand and become proficient using skills, processes, and practices required for scientific inquiry and the application of science. This includes the skills necessary for reading comprehension, argumentation, communication, collaboration, computational thinking, mathematical analysis, and technology fluency.

	Specific Curriculum Outcomes	Cognitive Level
PK 1	Construct meaning from science-based informational text.	Applying
PK 2	Compose written reports and arguments to effectively communicate scientific thinking.	Creating
PK 3	Design an investigation to examine a relationship between variables.	Creating
PK 4	Apply the engineering design process to develop a technical solution that addresses a need.	Applying
PK 5	Conduct investigations safely to collect data that can be used to answer questions or learn scientific concepts.	Applying
PK 6	Analyze data to determine patterns, trends, and causal relationships.	Analyzing
PK 7	Evaluate, with support, the strength of evidence resulting from a scientific investigation.	Evaluating

Enduring Understandings

Students will understand that

- ❖ Scientists look for repeated patterns and relationships in data (especially those that are cause and effect) to help them understand natural phenomena and predict outcomes.
- ❖ Science involves asking questions, predicting, and testing the prediction by collecting evidenc.
- ❖ Engineering uses the design process to solve real-world problems or to meet a need.
- ❖ *Evidence* in science is the qualitative and quantitative data collected during investigations.
- ❖ Scientists repeat experiments to see if they can get similar results, including measurements, each time.
- ❖ A scientific error is different from a mistake and is often caused by not controlling variable.
- ❖ The characteristics of scientific writing help avoid vagueness, bias, and opinion and enable other scientists to verify a study by repeating and/or expanding upon it.

Critical Thinking Prompts

- ❖ How are scientists creative?
- ❖ Why are scientists interested in cause and effect?
- ❖ What part of doing science is the most interesting to you?

Introduction

When considered collectively as a set, specific curriculum outcomes PK 1–7 reflect the skills and competencies necessary for scientific inquiry and engineering design. These outcomes describe what students are expected to “know how to do.” Specifically, students should know how to design an experiment with consideration of variables (SCO PK 3), perform investigations safely, record data effectively and without interpretation (SCO PK 5), analyze and interpret data (SCO PK 6), and evaluate data (SCO PK 7). SCO PK 1 and SCO PK 2 address the communication aspect of inquiry, but are designed to target reading and writing. Students should also have the opportunity to use the engineering design process (SCO PK 4) that, while similar to the experimental design process, differs in that it is used to seek solutions to human problems. Figures 19 and 20 depict scientific inquiry and design processes and their associated specific curriculum outcomes. A more detailed description of scientific inquiry can be found on pp. 26–27. An explanation of problem-solving in science and engineering is on pp. 28–29.

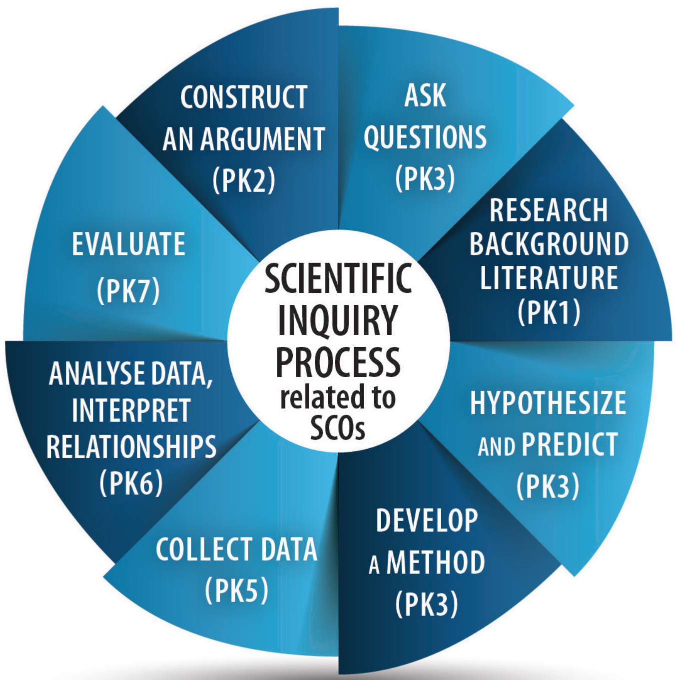


Figure 19. Scientific inquiry process related to SCOs

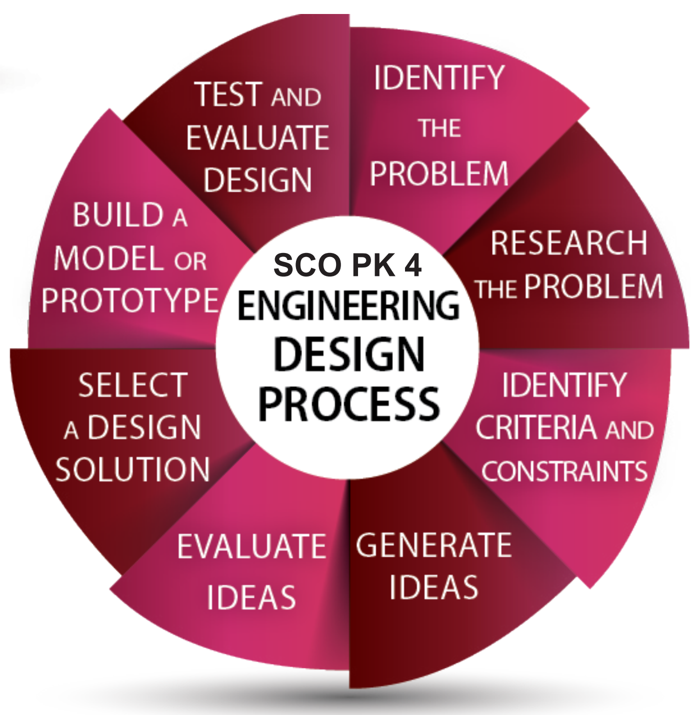


Figure 20. Engineering design process

Introduction

The table below provides links between the Procedural Knowledge specific curriculum outcomes and other subject areas. It also shows connections to Grades 7 and 8 science. This information is to help teachers build upon students' previous learning and see potential opportunities for integrating science with other subjects.

<table>
<tr><th>SCI 9 SCO</th><th>Course</th><th colspan="2">Related Specific Curriculum Outcomes</th></tr>
<tr><td>PK 1</td><td>7 ENG</td><td>SCO 7</td><td>Use research strategies to find information for specific purposes.</td></tr>
<tr><td>PK 2</td><td>9 ENG</td><td>SCO 8
SCO 10</td><td>Construct a range of written and media texts (narrative, expository, persuasive, and poetry).
Use self, peer, and/or teacher critical feedback to enhance personal text.</td></tr>
<tr><td rowspan="3">PK 3</td><td>7 SCI</td><td>SCO PS 3</td><td>Design and conduct experiments to explore methods of separating mixtures and solutions, and extend the impact of those methods on society and the environment.</td></tr>
<tr><td>8 SCI</td><td>SCO PS 1</td><td>Design an investigation to demonstrate an understanding of fluid viscosity.</td></tr>
<tr><td>9 MAT</td><td>SCO SP 3</td><td>Develop and implement a project plan for the collection, display, and analysis of data by formulating a question for investigation, choosing a data collection method, selecting a population or sample, collecting the data, displaying the collected data in an appropriate manner, and drawing conclusions to answer the question.</td></tr>
<tr><td rowspan="2">PK 4</td><td>7 SCI</td><td>SCO PS 6</td><td>Create a prototype of a device that will provide a solution to a practical heating or cooling problem.</td></tr>
<tr><td>8 SCI</td><td>SCO PS 3
SCO ESS 2</td><td>Create a prototype of an object that floats to analyze the effects of forces on objects in fluids.
Use the design process to demonstrate how water movement shapes our landscape.</td></tr>
<tr><td rowspan="2">PK 5</td><td>7 SCI</td><td>SCO PS 3
SCO PS 5
SCO ESS 3</td><td>Design and conduct experiments to explore methods of separating mixtures and solutions, and extend the impact of those methods on society and the environment.
Conduct experiments to describe the effect of heat on different forms of matter.
Investigate the characteristics of soil and soil conditions that affect its formation and degradation.</td></tr>
<tr><td>8 SCI</td><td>SCO PS 2
SCO PS 5</td><td>Compare the density of various substances qualitatively and quantitatively.
Examine the properties and behaviour of visible light.</td></tr>
</table>

SCI 9 SCO	Course	Related Specific Curriculum Outcomes	
PK 6	7 SCI	SCO PS 1 SCO ESS 1	Distinguish between pure substances and mixtures using the particle theory of matter. (This is classification.) Identify the characteristics between rocks and minerals. (This is classification.)
	8 SCI	SCO PS 2	Compare the density of various substances qualitatively and quantitatively.
	7 MAT	SCO PR 2	Create a table of values from a linear relation, graph the table of values, and analyze the graph to draw conclusions and solve problems.
	8 MAT	SCO N 3 SCO N 4	Demonstrate an understanding of percents greater than or equal to 0%. Demonstrate an understanding of ratio and rate.
	9 MAT	SCO N 1 SCO N 3 SCO PR 1 SCO PR 2 SCO PR 7	Demonstrate an understanding of powers with integral bases (excluding base 0) and whole number exponents by ... Demonstrate an understanding of rational numbers by • comparing and ordering rational numbers; • solving problems that involve arithmetic operations on rational numbers. Generalize a pattern arising from a problem-solving context using linear equations and verify by substitution. Graph linear relations, analyze the graph, and interpolate or extrapolate to solve problems. Model and solve problems using linear equations of the form • $ax = b$; • $x / b = a, b \neq 0$
PK 7	9 MAT	SCO SP 1 SCO SP 2	Describe the effect of bias ... on the collection of data. Select and defend the choice of using either a population or a sample of a population to answer a question.

PK 1		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

Procedural Knowledge

PK 1 Construct meaning from science-based informational text.

Achievement Indicators

Students who have achieved this outcome should be able to

a. explain the purpose for their reading;
b. independently locate information in scientific text;
c. discriminate between relevant and irrelevant information;
d. ask questions about what they have read;
e. interpret information presented in text features, not limited to, but including tables, graphs, charts, and diagrams;
f. summarize (in their own words) information presented in written text;
g. find information in multiple sources to support a position;
h. demonstrate comprehension of scientific concepts and vocabulary presented in text by answering questions that are literal, inferential, and evaluative in nature.

Guiding Questions

❖ Where do we find scientific information?
❖ How do we read informational texts for understanding?

Citizenship	Communication ✓	Personal-Career Development
Creativity and Innovation	Critical Thinking	Technological Fluency

Elaborations

“When we write, we compose thoughts on paper. When we read, we compose meaning in our minds.” [9]

Students can expand their knowledge of scientific concepts and phenomena, and gain insight into science by reading. They can apply this insight to think critically about an issue or develop a new perspective. Reading science requires knowing how to interpret, summarize, and infer meaning from informational text. For the purpose of this document, *text* refers to any form of written work and includes digital and non-digital forms. *Informational text* is a form of non-fiction that can be found in textbooks, reference books, science magazines, blogs, and websites. Its purpose is to relay facts or information. The information presented usually focuses on a specific topic (e.g., electricity, animals, space) and frequently includes specialized, technical vocabulary. Unlike other forms of non-fiction (e.g., biographies, narratives, instruction manuals), informational text extensively relies upon features such as graphs, diagrams, charts, photographs, annotated illustrations, sub-headings, and vocabulary to help communicate a message. In order to make meaning of informational text, students must develop the necessary skills for reading these text features.

To become proficient readers in science, students need frequent opportunities to read and interact with different types of text. They should be explicitly taught a variety of reading strategies, such as considering the purpose of their reading, activating prior knowledge, stopping and consciously thinking about what was read, asking questions, creating pictures in their mind as they read, summarizing brief sections of text, and making notes in the margins. Rather than have students copy or recite definitions of new vocabulary, teachers should use strategies that encourage deeper comprehension (e.g., introduce some of the vocabulary prior to reading, provide brief explanations on word origin or meaning, associate words with images or analogies, have students write their own explanations or compose a nonlinguistic representation). Word walls, interactive websites (e.g., Quizlet.com), and computer applications can be used by students to help them retain key terminology. A useful strategy when modeling the interpretation of graphs and diagrams is for teachers to verbalize their thinking. The more complex the text, the more students need to interact with it.

Specific curriculum outcome PK 1 is to be integrated throughout the Grade 9 Science curriculum. When assigning questions that accompany a reading, the purpose of the questions and the cognitive demand being placed on the reader should be considered. *Literal questions*, which require students to recall or extract specific information from the text, are considered to be Level 1 questions. While these are considered to be lower level, they are necessary when students are developing an understanding of a new topic. Assessment of reading comprehension at this level usually involves totaling the number of correct responses. *Inferential questions* (Level 2) require students to connect ideas in order to interpret information that is implied but not explicitly stated. *Evaluative questions* are Level 3 in nature. These questions place the highest cognitive demand on students by requiring them to make a judgment about the content or synthesize information with other knowledge or experiences. Evaluative questions would naturally accompany readings within the context of topics addressed by SCO NoS 2 and SCO DP 2. Students are expected to respond to questions from all three levels, and it is recommended that teachers use exemplars and model how to interact with the text when answering questions that are inferential or evaluative in nature.

Type of Question	Cognitive Level	Description	Example Question
Literal	1	reading “the lines”	• What, when, who, where, how
Inferential	2	reading “between the lines”	• Why? • What is the problem?
Evaluative	3	reading “beyond the lines”	• What is the most important idea in this article?

PK 2		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

Procedural Knowledge

PK 2 Compose written reports and arguments to effectively communicate scientific thinking.

Achievement Indicators

Students who have achieved this outcome should be able to

a. distinguish between a scientific argument (i.e., question, claim, evidence, explanation, and rebuttal) and the common use of the term argument (i.e., disagreement);

b. compose written technical reports that clearly communicate the results of a scientific investigation using conventional organization (i.e., title, introduction, materials and methods, results, discussion/conclusion), features of scientific writing (e.g., word choice: objective, non-ambiguous language, non-emotive);

c. demonstrate proficiency using informational text features and scientific writing conventions. This includes

- creating purposeful tables, graphs, models, and diagrams (e.g., Bohr and Lewis diagrams, electrical circuits) in a manner that clearly communicates scientific concepts and the nature of data, trends, and other relationships,
- applying annotations (i.e., brief notes) and features of tables, graphs, and diagrams (e.g., titles, labels, legends) in a manner that clarifies the meaning of the content,
- using the International Union of Applied and Physical Chemistry (IUPAC) conventions when naming elements, ions, and compounds (i.e., ionic compounds formed from the first 20 elements and simple, common molecular compounds such as O_2, CO_2, H_2O),
- using the International System of Units (SI) conventions when writing units of measurement;

d. understand and avoid plagiarism;

e. revise their writing to improve communication of the message.

Guiding Questions

❖ What is a scientific argument? Why is it important in science?
❖ What are the key characteristics of scientific report writing?
❖ Why do scientists follow special rules for writing names of living and non-living things, chemical formulas, and units of measurement? What are some of those rules?

Citizenship	Communication ✓	Personal-Career Development
Creativity and Innovation	Critical Thinking ✓	Technological Fluency ✓

Elaborations

Whereas reading is the input of information, writing is a communication skill that involves the output of information. Writing activities in the science classroom can have many purposes: to develop technical writing skills, to develop critical thinking skills used for scientific reasoning (i.e., argumentation), to process new knowledge (i.e., for learning), and to demonstrate what has been learned (i.e., for summative assessment). To meet specific curriculum outcome PK 2, students must compose written reports and arguments.

Scientific argumentation is "a critical-thinking skill that helps students propose, support, critique, refine, justify, and defend their positions about issues. . . . [It] is a natural element of scientific inquiry."[14] Logical reasoning is implied in argumentation, which is fundamental to the process of science. Written arguments can be in the form of lab reports, which are a natural continuation of the inquiry process. They can also be based on an issue or development in science or technology that is being examined while students are working towards SCO DP 1 and 2 (see p. 81 for examples). Not all science-based reports are argumentative in nature. This is true for some lab investigations that are not hypothesis-driven and research reports that review a topic such as invasive species.

In some lab reports and published scientific papers, the writer makes a claim that a hypothesis is to be accepted or rejected. The author builds this argument using logical reasoning supported by data that was collected and analyzed during the investigation. Analyzed data (not raw data) is scientific evidence. The discussion section of a report is the heart of the argument. Publishing a scientific paper enables a scientist to have their research and scientific reasoning reviewed, replicated, challenged, and validated by other members of the scientific community. This peer review process is the rebuttal portion of the scientific argument and will be taught in later grades. However, intermediate teachers can discuss the concept of peer review with students as it ties in with SCO NoS 1.

The organization and style of scientific writing emphasizes clarity, objectivity, and the use of specialized technical language. The writer strives to ensure that the message communicated is clear and unambiguous. To develop proficiency with technical writing, students at this level should be provided with opportunities to practise skills specific to individual sections (e.g., writing a sequential procedure, recording observations, interpreting patterns and trends in graphed data, and formulating a discussion guided by teacher prompts) before completing a whole report. The use of exemplars and gradual release of responsibility for learning (p. 32) are recommended as instructional strategies. Teachers should explicitly teach students how to avoid plagiarizing the work of others.

Implicit in this outcome is the application of rules and conventions for nomenclature (i.e., naming organisms and chemicals) and units of measurement, as well as construction of effective tables, graphs, annotated diagrams, and other informational text features. Also implied within "effectively communicate" is the quality or clarity of writing based on criteria such as word choice, organization, fluency, and mechanics.

In addition to learning technical or scientific writing, students in Grade 9 should be provided with opportunities to write for the purpose of learning science (e.g., a narrative describing the path of a nitrogen or carbon atom through a matter cycle or the path of an electron in an electrical circuit, a reflection in a science journal regarding what they have learned about the process of science, a mind-map depicting what they learned regarding sustainability of ecosystems). These writing activities help students process and internalize the scientific concepts being examined. Teachers should consider the intended purpose of writing when deciding if student work should be assessed and if an assessment should be formative or summative.

PK 3		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

Procedural Knowledge

PK 3 Design an investigation to examine a relationship between variables.

Achievement Indicators

Students who have achieved this outcome should be able to

a. use the following vocabulary appropriately: *control, hypothesis, dependent variable, independent variable, prediction, test, variable,* and *variables to be controlled* (i.e., possible *confounding variables);*

b. propose descriptive and causal questions;

c. identify independent (cause) and dependent (effect/responding) variables;

d. formulate hypotheses (i.e., testable statements identifying cause and effect relationships) from causal questions;

e. recognize that only one variable (the independent variable) is manipulated during the course of an experiment;

f. propose a control for a test where appropriate;

g. predict expected outcomes of an experiment;

h. identify possible confounding variables (i.e., ones with unintentional effects on the dependent variable);

i. describe how several possible confounding variables will be controlled;

j. write step-by-step directions that can be followed by a peer to complete a familiar task;

k. design or adapt a simple procedure that will allow for the collection of appropriate data (i.e. measurements of response of the dependent variable) that can be used to support or refute the hypothesis;

l. analyze and evaluate the design of an unfamiliar experiment (e.g., identify the hypothesis, variables, errors in design).

Guiding Questions

- ❖ Is my hypothesis testable? Does it suggest a relationship between two variables?
- ❖ What is a variable? What is the difference between an independent and a dependent variable?
- ❖ What does it mean to *control* a variable? Why is this important?
- ❖ Are there variables that might affect my results that I forgot to control?
- ❖ Does my design ensure that I am collecting the data that will help me answer my question?
- ❖ Is my procedure detailed enough that someone else can follow it?
- ❖ How many times should I repeat my experiment before I am sure that my data is reliable? Why this many times?

Citizenship	Communication ✓	Personal-Career Development
Creativity and Innovation ✓	Critical Thinking ✓	Technological Fluency

Elaborations

SCO PK 3 focuses on the initial stages of inquiry during which questions are generated, hypotheses are proposed, a procedure is adapted or developed, and predictions are made. At the intermediate level, most experiments that students design will be those that examine direct cause and effect relationships. In these experiments, the independent variable causes an effect in a second variable, the dependent variable. To design an experiment, students will need to be able to distinguish between the independent variable, dependent variable, and variables to be controlled. Teachers should help students transfer their understanding of variables from math class to science investigations. Variables are represented by words and symbols. Variables may be expressed in units, which also have symbols. This is often confusing to students and needs to be explicitly taught (e.g., electrical current symbol is *I*; unit is amperes or amp, which has a unit symbol A).

A *variable* is anything in an experiment that can be changed.
Independent variable: the variable that **causes** a change in another variable. This is the only variable to be manipulated by the experimenter. A component of experimental design is deciding the variations to be used for the independent variable (e.g., temperatures of 1^0C, 5^0C, 10^0C, 20^0C).
Dependent variable: the responding variable that is **affected** by the independent variable. The experimenter observes or measures any changes that occur.
Variables to be controlled: in order to be certain that the independent variable is truly causing the observed effect on the dependent variable, all other variables must be controlled or kept constant. Variables that are not properly controlled can inadvertently affect the results and are sometimes called *confounding variables.*

Experimental Question	Independent Variable	Dependent Variable	Variables to Be Controlled
Does the amount of sugar in a yeast solution affect the amount of carbon dioxide gas produced?	amount of sugar	volume of carbon dioxide produced	temperature, amount of yeast, time, amount of water in yeast solution

It is a misconception that hypotheses are "guesses." *Hypotheses* are tentative, testable explanations that answer causal questions. Causal questions include "What affects?" or "What causes?" or "Why?" as opposed to descriptive questions such as "Which?" or "How many?" or "What colour?" The hypothesis proposes or explains a possible causal relationship between the independent and dependent variables. A *test* is then designed for the hypothesis. A *prediction statement* describes what is expected to happen during the test if the hypothesis is correct. The direction of change (i.e., increase, decrease, or no change) should be part of the prediction.

Causal question: What affects the resistance of a wire?
Hypothesis: The length of a wire affects its resistance.
Test: I will measure resistance using wires of increasing lengths.
Prediction statement: Increasing the length of a wire will result in an increase in the resistance.

If . . . then statements are traditionally used to write hypotheses, but this form is not necessary, and it is difficult for students in the intermediate years to write properly due to the complexity of the language required.
Correct: **IF** the thickness of a wire affects its resistance (hypothesis), and I measure the resistance using wires of different thicknesses (test), **THEN** resistance will decrease as the thickness of the wire increases (prediction).
Incorrect: **IF** I increase the thickness of a wire (actually the test), **THEN** its resistance will decrease (prediction).

Assessment for SCO PK 3 may be based on a student's written design, even if they do not perform the experiment. This allows for a greater possibility of questions and designs without the limitations of materials, time, and safety concerns. However, when students perform experiments that they have developed, make mistakes, and evaluate and modify the procedure as needed, they experience the full benefit of the inquiry process. It is recommended, therefore, that students should perform at least one experiment of their own design during the school year. Student-developed experiments may also be used to assess SCOs PK 5–7. Science fair projects, whether or not students participate in the science fair, are opportunities for students to work towards achievement of this outcome. Investigations that have been previously completed in class, or are taken directly from another source, are **not** suitable for assessment.

PK 4		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

Procedural Knowledge

PK 4 Apply the engineering design process to develop a technical solution that addresses a need.

Achievement Indicators

Students who have achieved this outcome should be able to

a. use the following vocabulary appropriately: *engineer, collaborate, constraint, design, problem, solution;*

a. identify examples of technologies (e.g., devices, equipment, structures, processes) that we use in our everyday life;

b. describe the need or practical problem to be solved;

c. identify the success criteria required for a solution;

d. identify the constraints that have been given (e.g., the materials that have been given, costs, size);

e. collaboratively brainstorm for possible solutions and select one that meets criteria;

f. design, independently or collaboratively, a product or device (i.e., solution) that would address the identified problem;

g. demonstrate the ability to encounter challenges with maturity, flexibility, creativity, and persistence;

h. communicate design concepts using their own technical drawings, models, digital images, prototypes, or other appropriate forms;

i. reflect upon the successes and difficulties experienced during the design process, both technical and those related to personal understanding and skill.

Guiding Questions

❖ What sorts of things can inspire creativity and innovation?
❖ What is engineering?
❖ Does every part of a device have a purpose?
❖ What is the process used to design an engineering product ?
❖ What behaviours are important in collaboration and group work?

Citizenship	Communication ✓	Personal-Career Development ✓
Creativity and Innovation ✓	Critical Thinking ✓	Technological Fluency ✓

Elaborations

Skills and Attitudes for Collaboration

- considering others' ideas
- criticizing ideas, not people
- accepting criticism
- being persuasive
- listening
- showing initiative
- asking for and offering help
- sharing ideas
- being responsible, completing tasks
- taking turns
- clarifying and asking for clarification
- following directions

The purpose of specific curriculum outcome PK 4 is to engage students in the practice of engineering design, and encourage creativity, flexible thinking, problem-solving, collaboration, and teamwork. It is an opportunity to introduce engineering as a potential career, and teachers may wish to have students research examples of problems that are addressed by various fields within this discipline (e.g., civil, mechanical, chemical, and electrical). Students should be encouraged to recognize that engineers include people from all genders, societies, cultures, and ethnicities.

Engineering design and scientific inquiry are similar in nature in that they are creative, problem-solving processes (pp. 28–29). They differ in that science is concerned with understanding how the physical world works, whereas engineering focuses on the application of science to design structures, devices, equipment, and processes that address practical problems. The type of questions that are characteristic of innovation and design might include the following: How could we design something to stop the spread of an invasive species? How could we make a substitute for plastic that is nontoxic and biodegradable? What safe, alternatives sources of energy could we develop to replace fossil fuels? How can we extend the life of a battery without compromising power or safety? How could we design an electrical circuit to . . . ?

Teachers may wish to introduce the engineering process by engaging the class in a broad, open challenge. At this developmental stage, students are often motivated by altruistic tasks and can be inspired by asking them to design something that would be beneficial to a parent, relative, pet, friend, or someone in need. The process, rather than the product, should be the focus. Later in the year, a more independent design activity can be integrated into one of the Grade 9 topics such as electricity. Extracurricular STEAM activities such as those suggested below can also be adapted to the classroom.

Another approach that can be used to introduce design to students is *reverse engineering*. This involves deconstructing a technology (e.g., switch, lamp, electronic toy, childproof medicine container, lint roller, eco-coffee cup, packaging) to identify and analyze the design of each component (e.g., material, shape, colour, size). Creative thinking is encouraged when students are challenged to suggest possible reasons for the specific design and to propose improvements or alternative uses for the item.

Examples of Design Opportunities within the Context of Grade 9 Science	
Biodiversity and Sustainability of Ecosystems	• Design a device for preventing the spread of an invasive species. • Design a product that can be used in a unique habitat, such as in a space station or on the ocean floor.
Patterns in Atoms, Elements, and Compounds	• Design a new material and suggest ways in which it might be used.
Understanding Electricity	• Deconstruct an electrical device (e.g., lamp or toy). • Design an electrical circuit to perform a specific function.
Other STEAM Opportunities	• PEI Provincial Science Fair • Destination Imagination™ • Future City Challenge (EngineersCanada) • Girls Get Wise (EngineersPEI)

PK 5

		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

Procedural Knowledge

PK 5 Conduct investigations safely to collect data that can be used to answer questions or learn scientific concepts.

Achievement Indicators

Students who have achieved this outcome should be able to

a. use the following vocabulary appropriately: *data*, *qualitative and quantitative observation*, *infer, results*, *unit*;

b. describe the purpose, question, or hypothesis guiding the investigation, and data to be collected;

c. follow procedural instructions with guidance;

d. describe their role on the investigating team;

e. apply safe practices when using techniques, equipment, and chemicals including

- handling and disposing of lab materials (as directed by the Workplace Hazardous Materials Information System [WHMIS 2015] and provincial regulations),
- following guidelines communicated by the teacher regarding appropriate use of personal protective equipment, behavioural expectations, and notifying the teacher of accidents and spills;

f. select and use appropriate equipment (i.e., labware, tools, apparatus, and computer technologies) to mix, set up apparatus, build circuits, measure, and collect data;

g. identify appropriate units for measurements, converting and changing scale of measurement where necessary (e.g., from mV to V);

h. record qualitative and quantitative observations in a systematic and organized manner (e.g., consider *before*, *during,* and *after* observations; use a table or bullets; record date, title, or other identifier for data; draw a labelled sketch);

i. problem-solve as necessary during investigations (e.g., determine the number of batteries required in a circuit, find the cause of a bulb not lighting, tighten a wire, improvise).

Guiding Questions

❖ What is the purpose of the investigation?
❖ What safety procedures should be followed?
❖ Which of the listed materials do I actually need?
❖ What data will be recorded? What are the units? How will it help answer the question being asked?
❖ How should I record my data so that another person can understand it later?

Citizenship	Communication	Personal-Career Development ✓
Creativity and Innovation	Critical Thinking	Technological Fluency ✓

Elaborations

Specific curriculum outcome PK 5 reflects the second stage of the scientific inquiry process, performing and recording (Table 4, p. 27). Well-designed hands-on lab investigations provide the intermediate learner with engaging opportunities to develop proficiency with manipulative skills (i.e., those involved with the handling of equipment and materials) while encouraging critical thinking and problem-solving skills. Classroom-laboratory experiences also facilitate student understanding of abstract scientific concepts such as static and current electricity, chemical change, and ecological diversity. They should be purposefully selected to integrate with specific curriculum outcomes CK 1–3.

By the end of Grade 9, students should demonstrate confidence and proficiency when
- making accurate measurements (e.g., length, mass, volume, time, temperature);
- using equipment such as filtrating apparatuses, pipettes, and thermometers;
- selecting and using appropriate glassware for measuring and mixing;
- using and caring for instruments including knowing their purposes, parts, and how to read their scales;
- employing safe practices when using chemicals and equipment and being familiar with WHMIS 2015*;
- connecting components (e.g., of electrical circuits) and setting up equipment.

Teachers should move students towards independently recording observations and measurements in a science journal or logbook rather than completing teacher-prepared tables and worksheets. Observations should be explicitly taught as *objective* descriptions of what one detects using the senses: sight, hearing, touch, and smell (taste is omitted for safety). It is good practice to observe before, during, and after a test is performed. Students should be guided to avoid inferring (interpreting) when recording observations. Observations are interpreted later during analysis (results) and when results are explained (in the discussion section of a lab report).

Observation: The colour changed from clear to pink when the two solutions were mixed together.
Inference: A chemical reaction was observed when the two solutions were mixed together.

Both teacher-directed lab activities and investigations designed by students (SCO PK 3) are suitable for this outcome. While online computer simulations should not replace all classroom-laboratory experiences, they can be used when safety, lack of equipment, or level of skill are limiting to the investigation and student learning. Viewing teacher-performed demonstrations does not meet this outcome.

* WHMIS is a system in Canada that provides information regarding safe use and storage of chemicals in the workplace. WHMIS 2015 aligns these guidelines with the Globally Harmonized System of Classification and Labelling of Chemicals (GHS), which is a worldwide system currently being used. Information regarding WHMIS 2105 and GHS can be found on the website for the Canadian Centre for Occupational Health and Safety (http://www.ccohs.ca).

Within the context of Grade 9 topics, students could	
Biodiversity and Sustainability of Ecosystems	• use a sampling technique to measure diversity (e.g., counts of species per unit area); • record qualitative and quantitative characteristics of plant species; • create a simple dichotomous key to classify organisms or objects; • use a digital or non-digital simulation to investigate population changes.
Patterns in Atoms, Elements, and Compounds	• investigate the properties of metals and non-metals, or of acids and bases; • identify an unknown pure substance by analyzing its chemical and physical properties.
Understanding Electricity	• explore open and closed circuits; • investigate static electricity; • build a variety of cicuits; • use a computer simulation to investigate Ohm's law.

PK 6

		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

Procedural Knowledge

PK 6 Analyze data to determine patterns, trends, and causal relationships.

Achievement Indicators

Students who have achieved this outcome should be able to

a. distinguish relevant data (e.g., measurements of independent and dependent variables, measurements necessary for calculations using a formula, characteristics that will be used to classify or group) from irrelevant data or information;

b. organize data (e.g., using tables, graphs, or graphic organizers) to help visualize patterns, relationships, and trends (link to PK 2);

c. determine the line of best fit;

d. prepare numerical data for analysis by performing basic statistical calculations where necessary (e.g., totals, averages, ratios, and percentages);

e. classify objects and systems according to similar characteristics (e.g., invasive species, biomes, families of elements, conductors versus insulators, metals versus non-metals, parts of a circuit);

f. compare and contrast data sets (e.g., obtained with variations of the independent variable or time);

g. describe and interpret patterns and trends in graphed data (e.g., voltage versus resistance, population graphs);

h. demonstrate understanding that trends visualized in plotted data can be expressed as mathematical equations (e.g., voltage (V), current (I), and resistance (R) have a directly proportional relationship seen as a straight line on a graph and described by the equation $V = IR$);

i. calculate an unknown variable by applying a mathematical equation (i.e., Ohm's law: voltage = current x resistance; $V = IR$);

j. infer if the state of a system is stable and at equilibrium, or in the process of change (e.g., by observing the behaviour of objects during induction of static charge and discharge, analyzing population graphs);

k. infer and explain cause and effect relationships (e.g., as seen in matter cycles, populations, current and static electrical systems).

Guiding Questions

- ❖ How do scientists look for patterns and relationships to explain natural phenomena?
- ❖ What is the problem? What am I looking for?
- ❖ What is given (the parts)? What is important? What is not important?
- ❖ How will I analyze the information? What have I done before?
- ❖ What have I learned about the relationship?

Citizenship	Communication	Personal-Career Development
Creativity and Innovation	Critical Thinking ✓	Technological Fluency

Elaborations

Analyze means to break material into its constitute parts and determine how the parts relate to one another and to an overall structure or purpose. Example outcome verbs that are synonymous with analyze include categorize, classify, compare, contrast, deduce, differentiate, discover, discriminate, distinguish, examine, group, infer, investigate, and organize.

Students will have opportunities to analyze when they read texts to make meaning (SCO PK 1), examine the risks and benefits of a scientific or technological development (SCO DP 1), and examine the impact of human activities on ecosystems (SCO CK 1). However, specific curriculum outcome PK 6 addresses procedural knowledge, and to meet this outcome, students must demonstrate that they know *how to* analyze data. In Grade 9 Science, graphical analysis and classification have been identified as the main areas of focus. Numeracy skills, essential for scientific analysis, should be reinforced (e.g., measuring, graphing, calculating, problem-solving) during analyzing where appropriate. Data refers to both primary (i.e., collected by the student) and secondary (provided by the teacher or from online sources).

As part of working towards SCO NoS 1, students will come to appreciate that science presumes that the world is orderly, follows consistent laws, and is able to be understood. Scientists look for patterns, trends, and causal relationships during their examination of natural phenomena, and then try to explain why they occur. Broadly speaking, patterns are repeats in structures, occurrences, or relationships. Trends are directional changes in patterns or relationships. A periodic trend, for example, is that the radii of metal atoms decrease across rows in the periodic table. Causal (i.e., cause and effect relationships) are those in which one factor causes a change in another factor or causes an event to occur. Causal relationships can take many forms such as direct (cause A precedes effect B), a chain reaction (cause A results in an effect B, which causes effect C and so on) or cyclic (cause A results in an effect B, which affects A).

Grade 9 science topics that lend themselves well to graphing are periodic trends (Patterns in Atoms, Elements, and Compounds), population changes (Biodiversity and Sustainability of Ecosystems) and Ohm's law (Understanding Electricity). At this level, students should interpret population graphs qualitatively and suggest possible reasons for the observed changes. Ohm's law describes the linear relationship between voltage (V), current (I), and resistance (R) for ideal conductors (i.e., those that exhibit a non-changing or constant resistance). This law is represented by the mathematical equation (voltage = current x resistance; $V = IR$).

Graphing

Students are introduced to linear relationships during Grade 7 math and build upon this understanding in subsequent grades. Ohm's law is a linear realtionship between voltage and current that can also be described as directly proportional when resistance is held constant. This type of relationship is commonly observed between variables that students will see many times in secondary science courses (e.g., mass versus volume of solids at a constant density; number of gas molecules versus volume at a constant temperature; distance vs. time at constant speed). Students should be able to recognize directly proportional relationships by the presence of common features. For example, when increasing voltage is plotted against current (under ideal conditions), the following will be observed:

- The line that results will pass through the origin (zero) and slope upward to the right.
- A change in voltage will result in a change in current by the same factor (e.g., multiplied by 2, 3, 0.5).
- The slope of the line represents the resistance; greater slope means greater resistance (students at this level can describe slope qualitatively).
- Ordered pairs for any point on the line can be used to calculate the resistance by applying the equation resistance = voltage/current (resistance is a constant in Ohm's law).
- The resistance will be the same at every point on the line.

Elaborations

These patterns are observed in other proportional relationships. The slope of a distance versus time graph is speed, while the slope of a volume versus mass graph is density (students would have been introduced to density in Grade 8 Science).

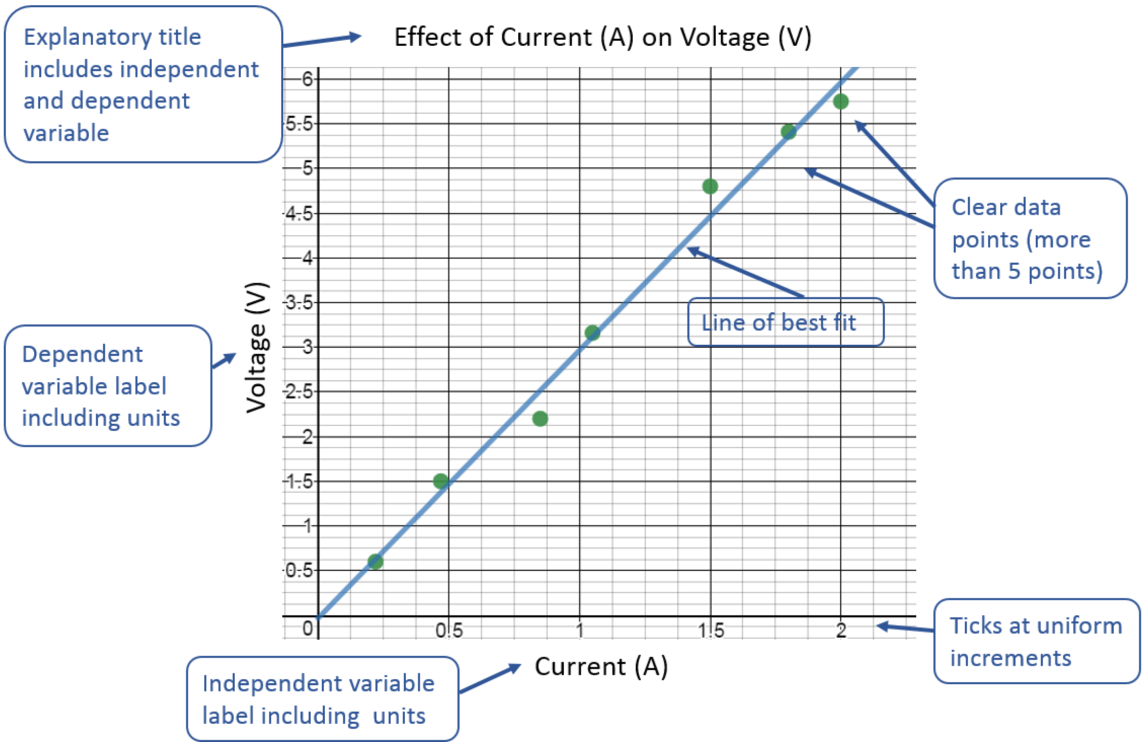


Figure 21. Exemplar graph

Classification

Classification is a method of analysis frequently used by scientists. Classification involves sorting, organizing, and identifying objects according to key characteristics. Higher order thinking occurs when students are classifying something new according to a list of criteria, determining the similarities and differences that will be used to classify an object, or creating a classification tool such as a branching diagram or a dichotomous key. During these activities, students need to reflect, ask questions, and make decisions. Teachers should consider the cognitive demand when designing instructional activities and assessment involving classification. Once the items in question and their characteristics become familiar to students, the cognitive demand lessens as students apply their understanding to identify rather than classify.

Elaborations

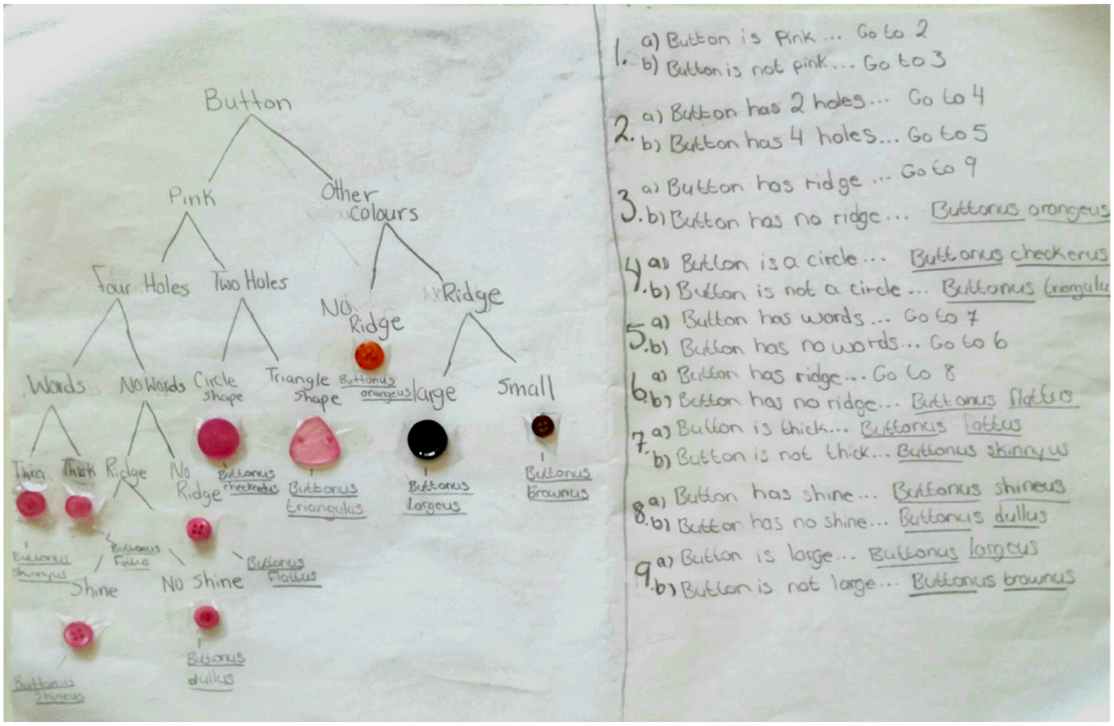


Figure 22. Student example of a branching diagram and dichotomous key

A number of opportunities to analyze exist within the three Grade 9 topics. Some of these are suggested in the following table.

Within the context of Grade 9 topics, students are analyzing when they	
Biodiversity and Sustainability of Ecosystems	• investigate the diversity (e.g., number of species) of an ecosystem; • develop branching charts and dichotomous keys to group living and non-living things according to their characteristics; • analyze population graphs.
Patterns in Atoms, Elements, and Compounds	• distinguish metals from non-metals by investigating their physical and chemical properties; • analyze periodic table patterns seen within groups and periods: atomic number; atomic mass; atomic structure (i.e., number of valence electrons, energy levels, and size); location of metals, non-metals, and metalloids; chemical and physical properties of families (i.e., alkali metals, halogens, and noble gases); • identify and classify properties (i.e., physical versus chemical) of substances; • distinguish between molecular and ionic compounds.
Understanding Electricity	• analyze the effect of similarly charged objects, oppositely charged objects, and objects without charge on each other; • investigate the causal relationship between length of wire, thickness of wire, or type of material, and resistance; • use graphs to analyze the linear relationship between voltage, current, and constant resistance.

Procedural Knowledge

PK 7		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

PK 7 Evaluate, with support, the strength of evidence resulting from a scientific investigation.

Achievement Indicators

Students who have achieved this outcome should be able to

a. use the following vocabulary appropriately: *bias, precision, random, scientific error*;

b. distinguish between scientific errors (e.g., those relating to imprecision of measurements and the inability to completely control all variables) and non-scientific errors (i.e., avoidable mistakes and accidents that affect the results);

c. identify one or two potential scientific errors, with prompting, that are specific to an investigation (e.g., species of plants in a survey are missed due to the time of year or size of the plant; there is a loss of voltage in all circuits due to resistance; difficulty in seeing a colour change; difficulty in controlling a variable);

d. explain why sampling techniques are used (e.g., in ecological surveys) and describe criteria of a good sampling technique (e.g., random, without bias, sufficient samples taken to represent the population);

e. qualitatively estimate, with justification, the extent of the impact of errors on the interpretation of data;

f. identify possible ways to address the identified errors and allow for improved data in future investigations.

Guiding Questions

- What is “good” data?
- What is bias? How does taking random samples prevent bias?
- Why is including a *control* in an experiment useful?
- What is the difference between a scientific error and a mistake?
- Were there variables that I didn’t control well?
- What could I change that would control these variables better next time?
- Which measurements vary when I repeat them?
- How did these errors affect my interpretation of the results?
- Is doing an experiment once enough “proof”? Why not?

Citizenship	Communication	Personal-Career Development
Creativity and Innovation	Critical Thinking ✓	Technological Fluency

Elaborations

Evaluate means to make judgments based on a set of criteria and standards. It involves critical thinking. Commonly used criteria are quality, effectiveness, efficiency, and consistency. Example outcome verbs that are synonymous with evaluate include: assess, conclude, critique, deduce, defend, evaluate, interpret, judge, justify, prove, and recommend.

Criteria used to evaluate data resulting from science investigations include *repeatability*, *reproducibility, accuracy,* and *precision*.

Repeatable means that an individual using the same equipment or apparatus obtains consistent (reliable) results or measurements.
Reproducible refers to whether or not the experiment performed elsewhere by another investigator will yield the same results.
Accuracy describes how close a measurement is to the true value; it is often related to controlling variables.
Precision is a measure of how close repeated measurements are to each other; it is related to reliability; it is related to sensitivity and resolution of a measuring instrument; it is independent of accuracy.

Evaluating the extent of scientific errors (i.e., the degree of accuracy and precision) is an important part of scientific inquiry, since errors directly impact the quality of evidence used to support the final conclusion or claim (links to SCO NOS 1). In high quality scientific investigations, careful attention is given to control variables so that accuracy is assured. To maximize precision, experimenters consider the appropriate sample size, sensitivity of measuring instruments, and the number of times an experiment is to be repeated. Even with careful experimental design, each scientific study has its own set of limits and degree of scientific error. Statistics are used to quantify the extent of scientific errors and the confidence in the results. A principle of science is that the extent of scientific errors are reported with the findings.

During the intermediate years, students should develop a very basic understanding that scientific errors include variation in measurements (i.e., precision) and an inability to control all variables in any experiment. They should understand that it is important that errors are identified and that the degree of their impact is evaluated. They should also recognize that scientists strive to reduce these errors to ensure quality of their results. While it is not required that students learn the specific terminology associated with scientific errors, teachers may wish to expose students to some of the vocabulary as another example where words used in science have specific meanings that differ from their use in everyday language (NoS 1).

When asked to evaluate an investigation, many students erroneously think that they are being asked to evaluate the experience. This often leads to evaluative statements such as, “It was fun,” “We needed more time,” or “I learned a lot.” The concept of evaluating data needs to be explicitly taught. Students should recognize that scientific errors differ from “mistakes” and that scientific errors are always present in science. Mistakes include forgetting to record data, miscalculating, spilling material, and setting up an apparatus incorrectly.

Mistakes do affect the final results and therefore interpretation of results. They should not be ignored by students in the evaluation process or in a lab report. However, students should be made aware that in a real-world experiment, the expectation would be that the experiment is disqualified and repeated, since the data would be considered invalid. This is an understanding that links to the nature of science curriculum outcomes. Good science is characterized by values such as precision, repeatability of results, and honest reporting of the findings.

By the end of Grade 9, students should be able to suggest a few scientific errors with prompting, and suggest ways that those errors could be reduced in future experiments. In a written report, the evaluation of the errors is placed in the discussion section; evaluating the strength of evidence is part of the scientific argument.

Content Knowledge

CK: Students will integrate knowledge and understanding of concepts related to life sciences, physical sciences, Earth and space sciences, and their real-world applications. They will think critically about these understandings to extend their knowledge of themselves and the world around them.

Specific Curriculum Outcomes	
CK 1	Analyze causal relationships between sustainability of life, biodiversity, population size, and cycling of energy and matter.
CK 2.1	Examine patterns in the structure and properties of atoms and their elements.
CK 2.2	Examine patterns in the composition of ionic and molecular compounds.
CK 3	Investigate to develop understanding of the principles of electricity.

Enduring Understandings

Students will understand that

- ❖ Populations of organisms are linked to one another in complex, self-regulating ecosystems whose stability can be affected by humans.
- ❖ All matter is made of atoms; there are fewer than 100 types of atoms.
- ❖ Arranging elements by their atomic number (as in the periodic table) reveals patterns in atomic structure, physical properties, and chemical properties.
- ❖ Atoms join together in specific patterns to form compounds
- ❖ Elements and compounds are pure substances that have characteristic sets of properties; humans exploit these properties to make things they want and need.
- ❖ Electrical energy results from the movement of electrons originating in atoms.
- ❖ The movement of electrons is dependent upon the laws of attraction and repulsion of charges; opposite charges attract and like charges repel.
- ❖ We are able to control electricity safely, and transform it into useful forms of energy such as heat, light, and mechanical energy by exploiting the relationship between resistance, voltage, and current.

Critical Thinking Prompts

- ❖ Are humans a part of nature? Why or why not?
- ❖ What is the carrying capacity of humans?
- ❖ How do we decide the boundaries of a system?
- ❖ If atoms are mostly empty space, how can objects be "solid"?
- ❖ What would life be like without electricity?

Introduction

Four specific curriculum outcomes (SCOs) describe the content knowledge that students are expected to know within the Grade 9 Science topics: Biodiversity and Sustainable Ecosystems (SCO CK 1), Patterns in Atoms, Elements, and Compounds (SCOs CK 2.1 and SCO 2.2), and Understanding Electricity (SCO CK 3). Students are expected to demonstrate their understanding of these topics of science by stating and recalling facts, conveying the meaning of vocabulary, applying scientific knowledge to solve familiar and unfamiliar problems, and analyzing contextualized problems.

The content that students are expected to knowledge should be seen as the context for specific curriculum outcomes grouped under Procedural Knowledge (SCO PK series) and Decisions and Perspectives (SCO DP series). For example, engaging students in a hands-on sampling activity to measure the number of species of plants in an area can be used to help them understand the concept of biodiversity (SCO CK 1) while simultaneously developing inquiry skills (SCO PK 5). Considering the importance of taking random samples would address SCO PK 7. When analyzing graphs related to changes in populations (SCO CK 1), graphing skills (SCO PK 6) can be reinforced. Analyzing "what if" scenarios relating to the carbon cycle and climate change supports increased understanding of the concept of matter cycles (CSO CK 1) as well as cause and effect relationships (SCK PK 6). A research report based on invasive species could be used to address SCO PK 1–2 (reading and composing written text) and the impacts of human activity on ecosystems, populations, and sustainability (SCO CK 1). More comprehensive projects can be used to target a greater number of outcomes. In a similar manner, SCO CK 2.1, SCO 2.2, and SCO CK 3 can be integrated with procedural and other specific curriculum outcomes.

The table below provides links between the Content Knowledge specific curriculum outcomes and previous science courses.

SCI 9 SCO	Course	Related Specific Curriculum Outcomes	
CK 1	7 SCI	SCO LS 1	Explain how different parts of an ecosystem interact and affect each other.
		SCO LS 2	Illustrate and analyze how food chains and food webs can be used to visualize the transfer of energy in an ecosystem.
		SCO LS 3	Propose actions to reduce the impact of human activities on a specific ecosystem.
		SCO ESS 2	Explain how the Earth's crust undergoes gradual and sudden changes over time. (Note: This links to matter cycles.)
	8 SCI	SCO ESS 1	Analyze the global distribution of water and its impacts on local environment.
		SCO ESS 3	Critique human impact on water systems in the environment.
		SCO PS 6	Analyze the different types of electromagnetic radiation and its impact on their [students'] daily lives.
CK 2.1 CK 2.2	7 SCI	SCO PS 1	Distinguish between pure substances and mixtures using the particle theory of matter.
		SCO PS 2	Describe the characteristics and applications of solutions.
		SCO ESS 1	Identify the characteristics and relationships among rocks and minerals.
	8 SCI	SCO PS 2	Compare the density of various substances qualitatively and quantitatively.
CK 3	7 SCI	SCO PS 5	Explain how heat is transferred by conduction, convection, and radiation in solids, liquids, and gases.

CK 1		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

Content Knowledge

CK 1 Analyze the relationship between sustainability of life, biodiversity, population size, and cycling of energy and matter.

Achievement Indicators

Students who have achieved this outcome should be able to

a. use vocabulary including, but not limited to, *abiotic, biodiversity, biome, biosphere, biotic, carrying capacity, competition, ecosystem, equilibrium, holistic, invasive species, limiting factor, matter cycle, population, sustainable ecosystem, sustainability, system and component, trophic levels*;

b. illustrate why photosynthesis and respiration are opposite chemical reactions and important to the sustainability of life;

c. demonstrate an understanding of the fundamental concepts of matter cycles and explain why they are important to the sustainability of life (e.g., they are mechanisms that “share” limited matter, such as carbon or nitrogen, between abiotic and biotic components of ecosystem; each cycle describes one element or nutrient essential to life; the element is found in different substances throughout the cycle; the length of time varies between parts of the cycle; there is no beginning nor end);

d. predict how a factor impacting one part of a matter cycle might affect the whole cycle or an entire ecosystem (e.g., increasing the amount of atmospheric carbon dioxide and changing the Earth’s climate);

e. analyze population changes by considering the interplay of births, deaths, and factors (e.g., competition, disease, availability of light or food) that limit the size of populations and influence carrying capacity;

f. describe the major human activities (i.e., habitat change, overexploitation, pollution, invasive species, and climate change) that have resulted in an unprecedented rate of decrease in biodiversity in recent years, with a particular emphasis on invasive species in PEI;

g. describe how changes in biodiversity (i.e., number of species and variation in individuals) affect the health and sustainability of ecosystems.

Guiding Questions

- ❖ What is a sustainable ecosystem? What have I learned about equilibrium and balance in nature?
- ❖ Why is sunlight important to the sustainability of life?
- ❖ How does nature recycle matter? Why is this important?
- ❖ What causes populations to fluctuate? What kind of patterns are observed in these fluctuations?
- ❖ What is biodiversity? Why is it important to ecosystem health?
- ❖ What are invasive species? Why are they a problem? Are they here in PEI? What can we do about them?
- ❖ How do changes in one part of an ecosystem affect other parts?

Citizenship ✓	Communication	Personal-Career Development
Creativity and Innovation	Critical Thinking ✓	Technological Fluency

Elaborations

Specific curriculum outcome CK 1 builds upon the Grade 7 Science unit, Interactions within Ecosystems. In Grade 7 Science, students were introduced to the concept of an ecosystem as an *interaction* between the biotic and abiotic components of an ecological system. In Grade 9 Science, students will deepen this understanding by examining

- the concepts of biodiversity and sustainability;
- cycling of matter through the biosphere;
- patterns in population growth related to carrying capacity and limiting factors;
- invasive species as an example of how human activities impact biodiversity and ecosystem sustainability.

During Grade 7 Science, students examined the conversion of the Sun's energy during photosynthesis and its subsequent transfer from producers (plants) through levels of consumers (e.g., herbivores, carnivores). They also studied food chains. When activating this prior knowledge, teachers should address misconceptions (e.g., the arrow in food webs demonstrates the direction of energy flow rather than "who eats whom"). Students will deepen their understanding during Grade 9 by considering that this flow of energy though *trophic levels* is essential to sustain life. Furthermore, they should recognize that the amount of available energy decreases at each level as it flows through the ecosystem (approximately 10% of energy is passed on; 90% is used at each level).

During Grade 8, students examined the water cycle, which is based on physical change (e.g., evaporation, condensation, transpiration in plants). This understanding is transferred to matter cycles in Grade 9. Students are not expected to memorize individual matter cycles, but rather develop the understanding that these cycles are the manner in which a finite amount of material is made available to all living things in the biosphere. Students should be able to describe features common to matter cycles (e.g., the element being cycled occurs in different substances), interpret simple diagrams of cycles that they have not previously seen, and predict possible effects caused by changes to one part of the cycle (e.g., how deforestation affects different parts of the carbon cycle). Activities that involve playing the role of a carbon or nitrogen atom can help students develop an appreciation that matter cycles have no beginning nor end. The carbon cycle should be connected to an examination of climate change (link to DP 1 and 2, and NoS 2).

The size of a population within an area depends upon the number of births, deaths, individuals moving in (*immigration*), and individuals moving out (*emigration*). These numbers respond to changes in a variety of factors (e.g., amount of available energy and matter in the form of food/sunlight/water, extent of competition, predation, or disease). These factors are considered limiting in that they determine a maximum number of individuals that can be sustained in an environment (i.e., *carrying capacity*). New populations that have not reached the carrying capacity exhibit exponential growth; students should recognize this form of growth, which can be described as a "J-curve" when graphed. As populations approach the carrying capacity, they equilibrate (the curve becomes "S-shaped") and often oscillate about this number. Students should be able to analyze simple population graphs that depict these patterns of population growth and decline (supports SCO PK 6).

Ecosystems are resilient and can often adapt to a new pressure if it is not too severe or does not occur at too fast a rate. However, human activity, such as the introduction of an invasive species, often results in the decline of one or more populations in an ecosystem by increasing the competition for essential resources (i.e., energy and matter). A change in one population can result in changes to the food chain and matter cycles, which in a domino cause and effect pattern, can impact other populations, and thereby decrease biodiversity. In Grade 9, biodiversity can be described as variation in the number of species within an ecosystem and variation of individuals within a population (genetic variation). Biodiversity increases the flexibility of an ecosystem and its ability to respond and adapt to changes. A decrease in biodiversity is considered a sign of poor ecosystem heath. Ecosystems with little biodiversity, and therefore simple food chains, are fragile. Ecosystems rich in biodiversity are robust. Students should be able to analyze scenarios, and justify their reasoning using what they have learned about matter cycles, energy flow, population growth, and the complexity of interactions between ecosystems in the biosphere.

CK 2.1		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

Content Knowledge

CK 2.1 Examine patterns in the structure and properties of atoms and their elements.

Achievement Indicators

Students who have achieved this outcome should be able to

a. use vocabulary including, but not limited to, *atom, atomic mass, atomic number, chemical and physical property, ductile, electron, element, elemental symbol, energy level (shell), group/family, malleable, matter, neutron, nucleus, period, periodic table, proton, valence electron*;

b. distinguish between physical properties (e.g., density, melting point, lustre, conductivity) and chemical properties (e.g., inert, reacts with water, reacts with oxygen) and provide examples of each;

c. contrast the three subatomic particles of the atom (i.e., electron, proton, and neutron) in terms of their location (i.e., inside or outside of nucleus), and their relative size and charge (i.e., +1, -1, 0);

d. explain briefly how the model of the atom has changed over time (NoS 1 link);

e. recognize that the 92 natural elements that exist on Earth are represented in the periodic table;

f. use Bohr and Lewis diagrams to illustrate differences between types of atoms;

g. examine periodic patterns in atomic structure (i.e., number of protons, electrons, energy levels, valence electrons) exhibited by the first 20 elements;

h. perform calculations involving the number of protons, electrons, neutrons, atomic number, and atomic mass;

i. deduce a representative element's group/family (i.e., alkaline metals, halogens, noble gases), atomic structure (e.g., number of protons, valence electrons, energy levels), and physical properties (e.g., metallic nature, conductivity, state) from its position in the periodic table.

Guiding Questions

- ❖ How many types of atoms exist? How do they differ from each other?
- ❖ What are the parts of an atom? Which part do you think is the most important? Why?
- ❖ Does the Bohr diagram represent what atoms really look like? Explain.
- ❖ How has our understanding of the atom changed over time?
- ❖ What is the difference between a physical and a chemical property?
- ❖ What causes different elements to have different properties?
- ❖ What are some of the patterns that appear when elements are arranged by their atomic number as in the periodic table?

Citizenship	Communication	Personal-Career Development
Creativity and Innovation	Critical Thinking ✓	Technological Fluency

Elaborations

Specific curriculum outcome CK 2 builds upon the Grade 7 Science unit Mixtures and Solutions and the Grade 8 Science unit Fluids. These units introduced students to basic concepts related to matter—pure substances (i.e., substances containing one type of particle, such as sugar), mixtures, particle theory of matter, density, and viscosity. During Grade 9 Science, students will deepen this initial learning by examining matter at the atomic level. Through inquiry, students will continue to investigate qualitative (e.g., colour, texture, state) and quantitative (e.g., boiling point, density, melting point) physical properties, but will now use these characteristics to classify elements (i.e., metals, non-metals, noble gases, halogens, and alkali metals). The concept of chemical properties (chemical reactivity) will also be considered during Grade 9 Science. However, emphasis upon understanding and distinguishing between chemical and physical change will be focused upon in Science 421, when chemical reactions are examined in greater depth.

Patterns in Atoms, Elements, and Compounds is an excellent topic to support student understanding of the nature of science (SCO NoS 1) by engaging students in activities that illustrate how knowledge, theories, and models related to atoms have been developed. Initial learning of atomic structure involves consideration of the three basic subatomic particles (i.e., electron, proton, and neutron) and their size, charge and location relative to each other. They should also be encouraged to consider the minuteness of the atom and the difficulty that this creates for scientists studying it and for the human mind to grasp.

Particle	Symbol	Location	Relative Charge	Actual Charge (C)	Relative Mass	Actual Mass (g)
proton	p^+	in nucleus	1^+	$+1.602 \times 10^{-19}$	1	1.67×10^{-24}
neutron	n^0	in nucleus	0	0	1	1.67×10^{-24}
electron	e^-	outside nucleus	1^-	-1.602×10^{-19}	~1/2000	9.1×10^{-28}

To facilitate understanding of the relationship of these components of the atom, students are traditionally required to draw simplistic variations of Bohr diagrams or models. Using models to develop understanding of the relationship(s) between components of a system (such as the atom) is a common practice in science. Students should be encouraged to use variations of these diagrams to support their learning.

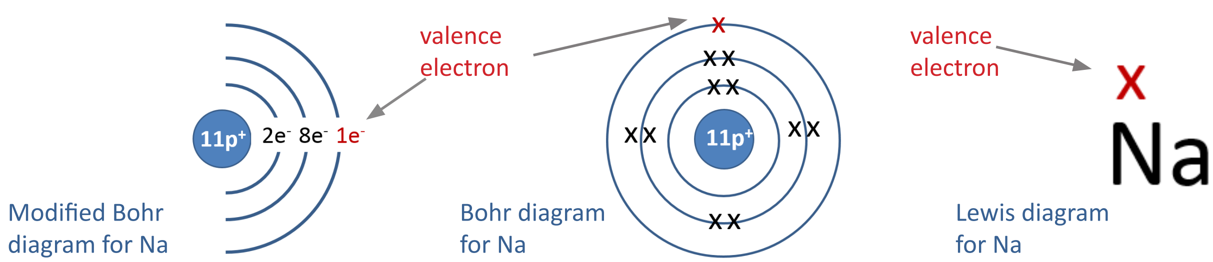


Figure 23. Atomic structure diagrams

Our understanding of atoms has progressed through the development of technologies (e.g., cathode ray tube, x-ray crystallography, accelerators, and detectors) that extended our ability to observe them (SCO DP 1 link). As new evidence is discovered, models are revised to incorporate the new knowledge. Students should be made aware that the Bohr model of the atom (developed in 1913) has been replaced by the quantum mechanical model. Scientists now know that electrons **do not orbit about the nucleus** like planets about a sun. Teachers should have students research and discuss the evolution of atomic models. However, students are not expected to memorize the specific details of these models or the history of their development. Rather, the focus should be on the concept of scientific models with consideration of their purposes and limitations (pp. 20–21).

Scientists look for patterns that help them understand and predict natural phenomena. Mendeleev's periodic table is an example of such scientific thinking. His organization of elements in the periodic table prior to understanding atomic structure revealed repeating patterns that enabled him to correctly predict the existence and properties of several elements before they were discovered. Students should explore periodic table patterns relating to atomic structure and the properties of elements.

CK 2.2		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

Content Knowledge

CK 2.2 Examine patterns in the composition of ionic and molecular compounds.

Achievement Indicators

Students who have achieved this outcome should be able to

a. use vocabulary including, but not limited to, *chemical change, chemical formula, compound, impure substance, ion, ionic charge, ionic compound, molecule, molecular compound, pure substance, ratio*;
b. recognize that chemical change is the formation of new substances by rearrangements of atoms;
c. use any variation of Bohr-Rutherford diagrams to illustrate the loss or gain of valence electrons during ion formation;
d. compare and contrast an atom with its ion;
e. demonstrate understanding that ions combine chemically in predictable ratios to form neutral compounds;
f. relate sharing of electrons with molecule formation and exchange of electrons with formation of ionic compounds;
g. use manipulatives to build molecules and ionic compound formula units;
h. determine the type of elements and ratio of atoms in a neutral molecular or ionic compound given either the formula, a structural diagram, or a pictorial representation;
i. deduce the formula of binary ionic compounds formed from the first 20 elements;
j. distinguish between ionic and molecular compounds using formulas, structural diagrams, models, or pictorial representations;
k. distinguish between pure substances (elements and compounds) and impure substances (mixtures) using pictorial representations.

Guiding Questions

- ❖ What is a chemical change?
- ❖ What is an ion? How does it differ from an atom?
- ❖ What is a molecule? What is molecular compound?
- ❖ How do ionic compounds differ from molecular compounds?
- ❖ What are pure substances?
- ❖ What are the patterns in which atoms combine to form compounds?

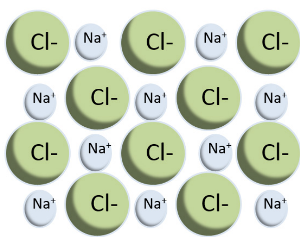
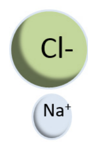
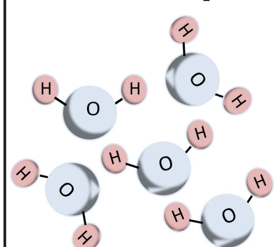
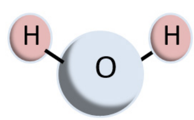
Citizenship	Communication	Personal-Career Development
Creativity and Innovation	Critical Thinking ✓	Technological Fluency

Elaborations

During Science 421, students will represent chemical reactions and the conservation of mass with balanced symbolic equations. Prerequisite skills required for constructing chemical equations include writing names and formulas of ionic and molecular compounds and using a periodic table. Students in Grade 9 will be introduced to naming and writing formulas for binary ionic compounds formed from the first 20 elements. Naming supports PK 2 (science writing conventions). During Grade 9, naming should be considered of secondary importance to analyzing the patterns found in the composition of compounds (i.e., the type and ratio of elements) and understanding formulas. For example,

- ionic compounds are composed of metal and non-metal ions;
- molecular compounds contain molecules that are formed from non-metal atoms combining;
- compounds are neutral or without a + or - change;
- within every compound, there is a consistent ratio of elements.

Manipulatives and periodic tables should be provided to students when they explore patterns and chemical formulas. Use these to have students create branching diagrams that distinguish between pure substances.

Pictorial Representation of Compound	Repeating Unit	Types of Atoms	Ratio
ionic compound sodium chloride (NaCl) 	formula unit 	metal & non-metal	1Na : 1Cl
molecular compound water (H_2O) 	molecule 	non-metal + non-metal	1O : 2H

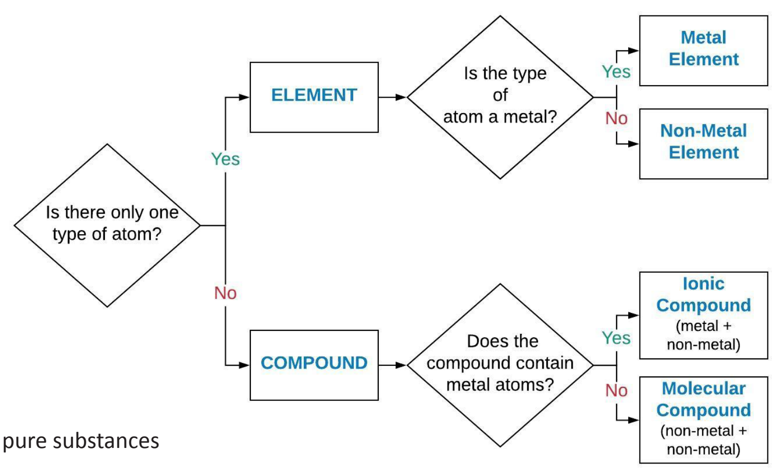


Figure 24. Classification of pure substances

CK 3		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

Content Knowledge

CK 3 Investigate to develop understanding of the principles of electricity.

Achievement Indicators

Students who have achieved this outcome should be able to

a. use vocabulary including, but not limited to, *attractive force, current, electrical charge, electrical energy, friction, fuse, grounding, lightning, load, Ohm's law, parallel circuit, repulsive force, resistance, series circuit, shock, short, source, static electricity, switch, voltage, wire*;
b. relate electricity to attractive and repulsive forces between charged particles (i.e., electrons and protons) that originate in atoms;
c. apply the rule “like charges repel; opposite charges attract” to predict the behaviour of charged objects on each other and on neutral objects;
d. recognize that movement of electrons, not protons, occurs in static and current electricity;
e. describe the distribution of charges in neutral and charged objects;
f. describe ways to create an imbalance of charge (e.g., friction and induction) and electrical discharge;
g. illustrate the movement of electrons in a conducting wire and the concept of resistance;
h. identify and describe the function of the components of an electrical circuit (i.e., load, source, wires, switch, and fuse);
i. apply the law of conservation of energy to electrical energy;
j. describe, with the support of diagrams, pathways of electrical current through a variety of circuits;
k. describe the flow of charges during the grounding of an object and the importance of grounding when working with electricity;
l. assess the risk of electrical shock or fire by considering the amount of voltage, resistance, and current in different situations;
m. examine the mathematical relationship between voltage, current, and resistance as described by Ohm's law (voltage = current x resistance; $V = IR$) (link to PK 6).

Guiding Questions

- ❖ What is charge? If atoms are neutral, what causes some materials to become electrostatically charged?
- ❖ How is static electricity similar to current electricity? How is it different?
- ❖ What happens between the wall switch and a lamp that is across the room?
- ❖ What are the parts of a circuit? How do they work?
- ❖ How are voltage, current, and resistance related and why is this relationship important?
- ❖ What causes an electric shock? How can one be prevented?

Citizenship	Communication	Personal-Career Development
Creativity and Innovation	Critical Thinking ✓	Technological Fluency ✓

Elaborations

Electricity (SCO CK 3) should be taught after atomic theory (SCO CK 2.1), during which students learn prerequisite concepts such as atomic structure, charge, electrons (negatively charged particles), protons (positively charged particles), and conductivity. The topic of electricity provides an opportunity for students to consider the process of science holistically as they make connections between scientific explanations or theories (SCO NoS 1), with the application of theories to create useful devices (SCO PK 4). This topic can also be used as the context for Decisions and Perspectives (SCO DP 1) by having students examine issues related to energy (e.g., non-renewable energy sources, global warming) and the prevalence of circuitry-based devices in today's society.

SCO CK 3 should be integrated with SCOs PK 4–6, and it is expected that students will be given ample opportunity to plan, design, draw, and construct a variety of circuits. Hands-on activities, role-playing, and visual representations such as computer simulations and videos facilitate student understanding of abstract concepts, including the movement of electrons in a circuit, and resistance. Teachers should consider having students design an electrical circuit that performs a specific task to meet SCO PK 4 (application of the engineering design process). Such activities encourage the development of problem-solving skills, persistence, and resilience if designed with this purpose in mind. It is important to help students develop strategies that can be used when they become "stuck" in the process of problem-solving. Some of these strategies that are used in scientific and engineering problem-solving processes include trial and error, further research (e.g., accessing information on the Internet), and collaboration (p. 57).

Electricity combines the chemist's understanding of the relationship of atoms, matter, and properties with the physicist's focus upon energy and forces (p. 23). Atoms are neutral because they have the same number of negatively charged electrons as positively charged protons (i.e., an equal number of opposite charges). In conductive materials (e.g., metals), the valence electrons of the atoms are less tightly held and move freely from atom to atom within the substance as net attractive or repulsive electrostatic forces are applied to them. The electrons in insulating substances do not move as freely, which explains the lack of conductivity that students would have observed when examining properties of substances as part of SCO CK 2.1. Students should be made aware that in both insulators and conductors, the protons remain within the nucleus. The nuclear forces holding protons in place are stronger than electrostatic forces moving electrons. The forces of electrostatic attraction and repulsion are the basis of what holds matter together and are responsible for chemical reactions and electricity. The behaviour of these forces is described by Coulomb's law (opposite charges attract; like charges repel).

Static electricity is created when there is an unequal distribution of oppositely charged particles in an object. Static electricity experiments provide the context for the learner to experience the constancy of scientific laws; students should create unbalanced charges in objects, predict their behaviours, and explore ways to restore neutrality (electrical discharge). Higher level thinking is encouraged when students are asked to apply information in the electrostatic series to develop experiments that enable them to determine an unknown charge on an object. The time alloted to the study of static electricity should be limited to ensure sufficient time is available for the examination of circuitry and engineering design.

Students should develop a basic understanding of voltage (electron potential or push), current (flow of electric charge), resistance (hindrance to flow of charge), and how the components of a simple direct current circuit function. Simulations such as those produced by phet.colorado.edu can be used to examine Ohm's law, resistance, and parallel versus series circuits without any concern of students creating unsafe circuits or damaging equipment. However, students are not expected to compare and contrast differences in voltage and current in parallel versus series circuits. Ohm's law should be connected to students' learning in math by connecting concepts such as linear relationships and algebra. This addresses SCO PK 6, p. 60.

An important aspect of students' understanding of electricity is recognizing safe and unsafe situations involving both current and static electricity. Students should determine the risk of lethal shock in different situations by considering the resistance of the human body (wet and dry), voltage levels, the amount of current, and potential pathways as equilibrium of charge is restored.

Decisions and Perspectives

DP: Students will evaluate personal, societal, environmental, ethical, and sustainability issues relating to the applications of science and technology from multiple perspectives. This includes exploring science-related career pathways.

Specific Curriculum Outcomes		Cognitive Process
DP 1	Examine the benefits and risks of scientific and technological developments.	Analyzing
DP 2	Defend decisions or judgments regarding scientific or technological issues, with consideration of multiple perspectives.	Evaluating
DP 3	Reflect on personal characteristics, skills, and opportunities that connect to a career in science.	Evaluating

Enduring Understandings

Students will understand that

- What we learn from science can lead to the development of new technologies that address human needs.
- Applications of science have both advantages and disadvantages.
- There must be ethical considerations when pursuing, and applying, science and technology; just because we can doesn't necessarily mean we should.
- Scientific knowledge is not an opinion, but how we should use science is based on opinion.
- Multiple perspectives can be "correct" and may offer alternative solutions to a problem.

Critical Thinking Prompts

- Which discovery or invention was the most harmful for the world? Which was the most beneficial?
- Who is responsible for taking care of the Earth?
- Who has the right to use the limited resources on Earth?
- What would happen if we just stopped progress for a while?
- How do we decide if the benefits of a new technology outweigh the risks?
- When is a perspective "correct"?
- How successful is a technology developed by one country if it adversely affects (directly or indirectly) another country?
- What characteristics do I have that would make me a good scientist?

Introduction

Scientific knowledge is not a matter of opinion. However, decisions regarding how we should apply science, or act upon what we have learned, are based upon opinions that are influenced by various personal, political, cultural, ethical, and economical perspectives.

The two specific curriculum outcomes included under Decisions and Perspectives address the decision-making process in the context of what we, as global citizens, should do in response to a particular situation. This process is shown in Figure 25. SCO DP 1 addresses the first part of this process and the concept that there are both risks and benefits associated with new developments in science and technology. This is true whether we are considering a product as basic as a battery or the application of genetic engineering. SCO DP 2 represents the final stages of the process and involves students making thoughtful decisions while considering the perspectives of others. SCO DP 3 is related to personal characteristics and careers.

Figure 25. Decision-making process

Early adolescence is a period of rapid, significant change in emotional, social, intellectual, and ethical development. The intermediate learner often uses rigid definitions for right and wrong, but during this developmental period is moving from decision-making based on social conventions to decision-making on personal values; they are attempting to define self. With the continued development of reasoning skills, these students are able to apply problem-solving strategies to unravel complex issues while reflecting upon feelings, emotions, and responsibility. Considering controversial and ethical dilemmas with their peers can also motivate and engage them during science classes. In time, students will come to appreciate that some questions raised by science are intricate and without a “right” answer. Such learning opportunities can facilitate the development of critical thinking and citizenship in students by providing a context for reflection of their own perspectives and those of others.

The table below provides links between the Decisions and Perspectives specific curriculum outcomes and other curricular areas. This information is to help teachers build upon students’ previous learning and see potential opportunities for integrating science with other subjects.

SCI 9 SCO	Course	Specific Curriculum Outcomes
DP 1–2	9 SS	SCO 9.1.1 Investigate how globalization affects Atlantic Canada. SCO 9.2.2 Analyze factors that contribute to the globalization of culture. SCO 9.2.3 Assess the impact of globalization of culture. SCO 9.3.2 Analyze factors that contribute to the globalization of economic activity. SCO 9.3.3 Demonstrate an understanding of how the globalization of economic activity affects Atlantic Canada and the global community. SCO 9.4.2 Analyze factors that contribute to environmental issues. SCO 9.5.1 Investigate the significance of the universal human rights movement in Canada and the global community.
	9 ENG	SCO 1 Justify a point of view using effective communication. SCO 2 Use a wide range of communication strategies and skills effectively in formal and informal situations. SCO 6 Evaluate how human rights are portrayed in a variety of texts.
DP 3	9 HEA	Refine personal goals and priorities relevant to learning and career paths. Create a learning plan for transition to senior high school. Analyze the potential impact of volunteerism on career opportunities.

Decisions and Perspectives

DP 1		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

DP 1 Examine the benefits and risks of scientific and technological developments.

Achievement Indicators

Students who have achieved this outcome should be able to

a. use the following vocabulary appropriately: *risk, benefit*, *advantage,* and *disadvantage*;

b. explain how science and technology interact and advance one another;

c. identify a technology or a scientific development that was created to address a human need or practical problem (e.g., plastics, disposable cups, fluoridated water/toothpaste, medicinal drugs, aerosol cans, batteries, the electrical circuit, planes, fossil fuels, nuclear power);

d. recognize that scientific and technological developments always have risks and benefits that are important to consider before the development is adopted;

e. propose questions that could be used to guide a risk and benefit analysis of new technology or scientific development (e.g., How will it be used? Is it toxic? How expensive is it? How will we dispose of it? Can it be “undone”? What alternate uses could it have?);

f. determine the advantages (benefits) and disadvantages (or risks) of a technological or scientific development.

Guiding Questions

❖ How are science and technology related?
❖ What is technology?
❖ How do science and technology influence our lives in positive and negative ways?
❖ What do we mean by risks and benefits?
❖ How can we maximize the benefits while reducing the risks when we implement technologies?

Citizenship ✓	Communication	Personal-Career Development
Creativity and Innovation	Critical Thinking ✓	Technological Fluency

Elaborations

Specific curriculum outcome DP 1 familiarizes students with the paradox that while science and technology help us solve problems, they often create new ones. Part of making decisions regarding the outcomes of science and technology requires an analysis of the risks and benefits. Students should examine sufficient cases throughout the year to develop the understanding that even simple technologies that we take for granted have advantages and disadvantages that must be considered. Batteries, for example, are advantageous in that they are portable and enable the use of electrical devices when electricity is not available. They are also relatively affordable and can be easily replaced. Their disadvantages are that they have a limited lifespan, contain corrosive chemicals, and can explode and cause fires. Furthermore, disposing of batteries can be problematic since the chemicals they contain are harmful to the environment and not suitable for landfill sites.

Students should develop an understanding of the close relationship between science and technology. Historically, science inquiry was often inspired by curiosity, with an end goal of understanding natural phenomena. In today's world, science investigations are rarely purely academic and are often linked to the desire to address a problem, need, or want of humans. It can sometimes be difficult to determine the boundaries of science and technology; science leads to the development of new technologies, many of which are then used to further advance scientific understanding.

By definition, technology is considered to be "human innovation in action" and enables us to modify the world around us to meet our needs and wants. Technology includes products, devices, and processes. This includes complex instrumentation used in science laboratories and hospitals; appliances; vehicles used for transportation; computer information technologies (CIT); tools such as pencils, hammers, flashlights; products such as medicine, cleaners, and fertilizers; materials such as those used in construction, packaging, and clothing; and processes such as water purification, treatment of disease, and those used in industry. When analyzing advantages and disadvantages of technologies, students should be encouraged to consider technology in the broadest sense and recognize that every technology incorporates scientific principles.

Examples of Science and Technology Advancements within the Context of Grade 9 Science Topics	
Biodiversity and Sustainability of Ecosystems	• internal combustion engine (i.e., one that uses fossil fuels) • forestry, agriculture, fisheries, or mining technologies (impact of large-scale industry) • transportation technologies (impact of mobility around the globe) • medical advancements (effect on population size)
Patterns in Atoms, Elements, and Compounds	• plastics • preservatives • steel and other alloys
Understanding Electricity	• alternate forms of energy (e.g., windmills, nuclear, solar) • disposable batteries • electrical circuit • computer technologies

Decisions and Perspectives

	DP 2	Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

DP 2 Defend decisions or judgments regarding scientific or technological issues, with consideration of multiple perspectives.

Achievement Indicators

Students who have achieved this outcome should be able to

a. use the following vocabulary appropriately: *perspective, ethical decision*;

b. identify past or current controversial issues that have resulted from an advancement in technology or science (e.g., use of a limited resource, cosmetic pesticides, adding fluoride to toothpaste and water, introducing non-native species for control of a pest, food packaging, using animals to test cosmetics);

c. reflect upon their personal perspective regarding an idea, issue, development, or outcome that has resulted from an advancement in science or technology (e.g., use of plastic bags, use of lawn pesticides, reliance on green energy);

d. recognize how perspectives are influenced by a variety of factors (e.g., age, gender, culture, socio-economics, values, beliefs, peer pressure, geographical region);

e. project the consequences of proposed decisions beyond the personal;

f. recognize that multiple perspectives can be correct;

g. demonstrate respect for the opinion, values, and ideas of others;

h. justify a decision from several points of view and with consideration of different perspectives;

i. reflect on why evaluating new ideas and developments with consideration of multiple perspectives can be valuable.

Guiding Questions

- ❖ Because science and technology enable us to do something, does that mean we should?
- ❖ What does *ethics* mean? What is an ethical decision?
- ❖ How do our backgrounds, experiences, and values influence our opinion?
- ❖ What are multiple perspectives concerning ...?
- ❖ What are the advantages of considering other people's perspectives when making decisions about science and technological developments?

Citizenship ✓	Communication	Personal-Career Development
Creativity and Innovation	Critical Thinking ✓	Technological Fluency

Elaborations

Arguably, the end goal of developing scientific literacy in our students is to enable them to make ethical decisions about what is reasonable to do or believe regarding scientific and technological ideas, issues, or developments. These decisions may have personal, societal, environmental, economic, or political impacts. Specific curricular outcome DP 1 addresses the analytical component of the decision-making process by asking students to examine the possible advantages (benefits) and disadvantages (or risks) of an outcome of science. Specific curriculum outcome DP 2 expects students to make justified decisions based on evidence and reasoning with consideration of varying points of view (who) and perspectives (how one feels) about an issue.

While science focuses on answering *why* and *how* something works, it is unable to answer *should we* questions, which are the basis of ethical decisions—ones that we make for the greater good. Science and technology have enabled us to create materials that last for thousands of years, use limited resources at unprecedented rates, and even change the genetic codes of species. Decisions about applying what we learn from science have the potential to impact everyone directly or indirectly. As such, the ethical application of science is the responsibility of society as a whole, and an overarching question for us is, "Just because science enables us to, should we?"

The intermediate years are an appropriate time to introduce students to the concept of ethics, as they are moving away from rigid definitions of right and wrong and beginning to formulate their own personal values. During Grade 9 Science, students should be given the opportunity to struggle with ethical dilemmas that do not involve overly complex scientific concepts, but will still encourage the development of critical thinking. Students will soon learn that deciding on the "right" course of action is not always as straightforward as it seems and that multiple perspectives can be correct. As globalization results in our close proximity in the real and virtual world, it is imperative that we encourage open-mindedness in our students. We need to help them understand that considering issues from different points of view is an essential component of critical thinking and can provide us with alternative solutions to a problem.

Engaging students in activities that enable them to consider the concept of point of view concretely (e.g., using optical illusions, pictures of items taken from a bird's-eye view versus a microscopic view, giving pieces of an image to different students and asking them to describe the whole) provides a segue into considering that we all "see" things differently. Students should be explicitly taught that culture, values, beliefs, and experiences in life help form our personal perspectives that we express as opinions. Providing students with an opportunity for self-reflection can help them develop an awareness of their own assumptions, values, and biases. Playing the role of various parties that will be impacted by a decision affords students the chance to see an issue through different lenses and leads to the realization of why other perspectives exist. Such learning encourages the development of empathy, tolerance, and flexible thinking—essential aspects of citizenship.

Examples of Prompts for Debates or Opinion Essays within the Context of Grade 9 Science
• Should we use genetic engineering to bring back extinct species? • Should extirpated species (i.e., no longer found in an area) be reintroduced to their place of origin? • Are zoos unethical or necessary to preserve species? • Should humans try to colonize another planet to solve the population problem? • Should lawn pesticides (or fertilizers, cosmetics, etc.) be banned? • Do the benefits of plastics outweigh the disadvantages? • Should the development of new chemical compounds be stopped? • Should we be adding chemicals (including preservatives) to things we consume? • Is it unethical for developed countries to dispose of their hazardous waste in developing countries, even with their permission? • Do the disadvantages of batteries outweigh the benefits? • Should solar energy replace all fossil fuel use? • What is the most harmful (or beneficial) invention in science or technology?

Decisions and Perspectives

DP 3

		Factual	Conceptual	Procedural	Metacognitive
1	Remembering				
	Understanding				
2	Applying				
	Analyzing				
3	Evaluating				
	Creating				

DP 3 Reflect on personal characteristics, skills, and opportunities that connect to a career in science.

Achievement Indicators

Students who have achieved this outcome should be able to

a. use the following vocabulary appropriately: *career, success,* and *resilience;*

b. identify what they enjoy about science;

c. describe character traits shared by scientists or engineers;

d. challenge stereotypes associated with scientists and engineers;

e. recognize that being self-aware, willing to learn, and open to possibilities are part of the mindset needed for well-being and an enjoyable career;

f. explain strategies they use when faced with a problem or difficult situation;

g. identify a variety of courses, activities, or occupations in science, technology, or engineering fields that they would like to explore further;

h. reflect on the skills and character traits that they have that would make them good scientists.

Guiding Questions

- ❖ What inspires me? What do I care about?
- ❖ What am I good at in science? What do I like to do?
- ❖ What challenges do scientists face?
- ❖ How do I demonstrate persistence when faced with a challenge?
- ❖ What high school courses and extracurricular activities would allow me to explore science?
- ❖ What jobs in science, technology, and engineering would I be interested in? Why?

Citizenship	Communication	Personal-Career Development ✓
Creativity and Innovation	Critical Thinking ✓	Technological Fluency

Elaborations

The Canadian Career Development Foundation (CCDF) defines *career development* as “the lifelong process of managing learning, work, leisure, and transitions in order to move toward a personally determined and evolving preferred future.” A person’s career is not their occupation, but a purposeful life journey that involves meandering, maneuvering, finding meaning, and building momentum.

Inviting scientists, engineers, and technology specialists from the community to tell their stories can inspire and help students see themselves in various science-related careers. Students should consider the character traits and habits of mind shared by successful individuals in these fields and be provided with the opportunity to reflect on which of these they possess. Reflection, critical thinking, and self-awareness are 21st-century career skills, but they do not come naturally to all individuals. Learning to reflect requires practice and patience.

Selected Habits of Mind for Science

- Curiosity
- Skepticism
- Integrity
- Persistence
- Resilience
- Creativity
- Innovation
- Diligence
- Flexibility
- Reflection

Grade 9 students are at the point of selecting high school courses. Having them envision a career pathway will ensure that decisions they make are well-informed. Intermediate students are introduced to the career development process during the Life Learning Choices strand in Grades 7–9 health. The resource for this strand, My Plan PEI (myplanpei.ca), provides students with opportunities to develop self-awareness, explore career pathways and labour market information, and plan high school courses. My Plan uses four questions to guide students:

- Who am I?
- What are my opportunities?
- What are my next steps and why?
- What is my action plan?

These questions encourage intention and optimism, which are essential to career development. Using tools such as STAC (see myplanpei.ca) can help students learn how to develop resilience and face challenges by having an action plan.

S	T	A	C
Situation	**Thought/Feeling**	**Action**	**Consequence/Result**
You have entered a science fair. Your science project, which you have put all your free time into, is due tomorrow. In a test, you discover a major flaw and realize the project is useless.	“What a waste of time!” “How could I have been so stupid for missing that detail!” “I’m so angry at myself!” Feeling discouraged and ready to quit. **or** Recognizing mistakes happen and this is the scientific process.	Throw the whole experiment in the trash. **or** Think about what could have been done differently. Start to make a plan for how to salvage the experiment. Talk to people in your network to brainstorm solutions.	Give up and miss the entire science fair. Let down people who were counting on you. **or** Go to see your teacher to explore how to turn this around. Enter the science fair with a new angle or demonstrate what learning took place even though the experiment did not turn out as planned.

Appendices

APPENDIX A: Authorized Resource:

Student Print Resources

- Scholastic Issues21 Series
  - *-Biodiversity*
  - *-Overpopulation*
  - *-Climate Change*
  - *-Energy*
- Pearson Investigating Science 9
- Pearson Big Idea High-Low Reader Series
  - *-Diversity of Life*
  - *-Habitats and Communities*
  - *-Chemistry*
  - *-Our Healthy World*

Teacher Resources

- *Science Surprise* and *TEACH Science Surprise* (pdf) by Lawrence Flammer
- *Science^3: A Science Student's Success Guide* by Rawle et al.
- *Taking Charge: An Introduction to Electricity* by Larry Schafer
- Scholastic Issues21 Series teacher guides
- Resource repository:

  -Science7–12/Courses/Science 9 (a shared Google Drive folder in cloud.edu)
  -learn.edu.pe.ca (Moodle)

APPENDIX B: The Scientific Literacy Continuum

The development of the knowledge, skills, and attitudes required for scientific literacy can be described as a continuum with four key stages: emergent, early, transitional, and fluent. These stages are described through the lens of each of the four foundations of scientific literacy; subsequent stages build upon earlier ones. The continuum is based on cognitive developmental patterns for primary, elementary, middle, and high school years with the recognition that learning is neither linear nor mirrored between students.

K–12 Scientific Literacy Continuum		Emergent	Early
Foundations of Scientific Literacy	**Nature of Science** *What is science?*	• Developing an understanding that we use our senses as a way of knowing • Developing an awareness that science helps us understand the natural and material world	• Developing an awareness of the scientific community that helps us understand the natural and material world • Developing an awareness that scientists follow a process to learn about the world
	Procedural Knowledge *What do scientists do?*	• Using their senses to learn about the natural and material world • Asking questions • Recording and interpreting observations • Playing (exploring and exhibiting curiosity) • Developing manipulative skills • Exploring measurement • Exploring patterns • Exploring similarities and differences	• Exploring the scientific inquiry processes (e.g., questioning, observing, recording, analyzing, interpreting, using models) • Exploring the importance of evidence and variables • Investigating cause and effect • Identifying similarities and differences • Developing more refined understanding of measurement • Exploring design • Using numeric, symbolic, graphical, and linguistic modes to communicate science ideas, plans, and results
	Content Knowledge *What have scientists learned?*	• Identifying characteristics of living things • Exploring properties • Exploring change	• Exploring science topics of personal interest • Developing an appreciation for science and the vastness of its contribution to understanding our world
	Decisions and Perspectives *How should we apply science?*	• Learning to respect self and others • Controlling physical interactions • Collaborating with and listening to others	• Extending focus beyond self and immediate environment • Becoming aware of the benefits and responsibilities associated with science and technology • Becoming aware of personal perspectives related to science issues • Recognizing and demonstrating respect for different perspectives

Transitional	Fluent
• Developing an understanding of science as a way of knowing (metacognition) • Beginning to develop an understanding of the significance of the processes of science in determining what is, and what is not, science • Beginning to critically think about scientific claims and the consequences of basing decisions on false claims	• Deepening understanding of science as a specific way of knowing that uses rational reasoning • Deepening understanding of the significance of the processes used in science • Demonstrating critical and skeptical thinking when presented with scientific and non-scientific claims in various media
• Discovering order in the natural world by analyzing and describing patterns, with support (e.g., linear and cyclic causal patterns, proportional relationships) • Developing skills for a more systematic approach to scientific inquiry • Developing experiential knowledge of STEAM (science, technology, engineering, art, and mathematics) related design • Developing communication strategies for science (presenting evidence and using reasoning and argumentation) • reflecting about personal skills and character traits that suit STEAM-related careers	• Discovering, recognizing, and analyzing patterns with increasing independence • Using deeper, more thorough, analysis and evaluation of design and scientific error • Performing experimental and engineering design with greater independence • Developing formalized communication strategies for science with more rigorous, logical argumentation and reasoning • Examining science career opportunities
• Developing a framework of understanding regarding the interdisciplinary concepts of science (matter, patterns in form and function, energy, equilibrium, change, systems, and models) and the interconnectedness of sciences and other STEAM fields	• Developing an understanding of foundational concepts within specialized core science (i.e., biology, chemistry, and physcis) and applied science fields (e.g., agriscience, oceanography)
• Reflecting on the risks and benefits of scientific and technological developments • Deepening an understanding of perspectives • Considering other perspectives when making decisions about the applications of science	• Critically thinking about the outcomes and applications of science with consideration of ethics • Making thoughtful decisions regarding science and technology issues • Critically evaluating perspectives using divergent and convergent thinking

APPENDIX C: Linking SCOs to Competencies

The chart below links verbs and phrases from science SCOs and achievement indicators to the essential graduation competencies. Use these cues to identify which competencies are being targeted when working towards a specific curriculum outcome.

APPENDIX D: Literacy Strategies that Support Science Learning

Literacy Strategies that Support Science Learning

Speaking and Listening

- Use discourse to promote scientific learning.
- Use think-pair-share and jigsaw to promote peer-to-peer talking.
- Have students work in groups to conduct inquiries.

Reading and Viewing

- Discuss prior knowledge and the purpose of reading.
- Provide a range of materials and opportunities for reading and viewing (e.g., texts, such as textbooks, case studies, magazine articles, lab instructions, and demonstrations).
- Help support student understanding of the textbook genre and the use of features such as the table of contents, glossary, index, subtitles, and pictures.
- Explicitly teach how to extract information from table diagrams and graphs (informational text).
- Provide opportunities to translate from informational text to written text.
- Model and use gradual release to teach note-taking.

Writing and Representing

- Discuss the topic before students begin writing.
- Use the gradual release of responsibility model with exemplars of scientific writing.
- Provide opportunities for students to produce parts of and whole procedural reports.
- Use templates and prompts (sentence stems) to guide students in writing justified arguments and explanations.
- Explicitly teach summarizing.

Assessment Literacy

- Model strategies for test writing (review the design and layout of the test and work within time limits).
- Teach test-question vocabulary (e.g., explain, list, describe, compare) to recognize what they are being asked to do.
- Model how to answer questions of different types.
- Teach students how to reflect on areas of strength and weakness and develop a concrete learning plan to move forward.
- Provide a variety of ways for students to demonstrate their understanding (including reports, presentations, written tests, and science portfolios).

Vocabulary

- Identify terms and phrases upfront that are critical to a topic.
- Provide instruction regarding the origin, a brief explanation, or a description of the new word.
- Associate the word with an image or other nonlinguistic representation of the word.
- Provide students with opportunities to provide their own explanations or nonlinguistic representations of the word or phrase.
- Discuss differences in the meaning of words shared by science and everyday language (e.g., law, theory, fact, variable).

APPENDIX E: Characteristics of ToS Assessment Levels

Assessment items can be classified according to three levels of complexity. Characteristics of each level are provided with examples in the following table.

LEVEL 1	LEVEL 2	LEVEL 3
Simple Recall Low Complexity	Application and Analysis Moderate Complexity	Innovative, Analytical, and Critical Thinking High Complexity
Level 1 items rely heavily on recall and recognition. These items typically specify what the student is to do. The student often carries out a procedure that can be performed mechanically and does not need an original method of solution. The following are some of the demands that items of “low complexity” might make: • Recall or recognize a fact, concept, or description. • Recognize an example of a concept. • Recognize an equivalent representation. • Perform a routine computation. • Follow a given procedure. • Evaluate an expression in an equation or formula for a given variable. • Solve a one-step word problem. • Draw or measure simple geometric figures. • Retrieve information from a graph, table, or figure.	Level 2 items involve more flexibility of thinking and choice. They a require response that has goes beyond the habitual and ordinarily have more than a single step. The student is expected to decide what to do using informal methods of reasoning and problem-solving strategies. Students are required to bring together skills and knowledge from various domains. The following illustrate some of the demands that items of “moderate complexity” might make: • Make connections between facts, terms, and concepts. • Represent a relationship between variables in more than one way (graphically, pictorially, mathematically). • Compare and contrast properties of a new item. • Group, sort, and classify according to criteria. • Explain and provide justification for steps in a procedure. • Analyze similarities and differences in novel scenarios. • Interpret a non-linguistic representation. • Retrieve information and then use it to solve a multi-step problem. • Retrieve information from multiple sources and use it to create a written summary.	Level 3 items place heavy cognitive demands on students by requiring them to engage in reasoning, planning, analysis, judgment, and creative thought. Students must think in an abstract and sophisticated way. The following illustrate some of the demands that items of “high complexity” might make: • Analyze patterns in data. • Solve a novel problem. • Solve a problem in more than one way. • Justify a solution to a problem. • Experiment to support or refute a claim. • Describe, compare, and contrast solutions to a problem. • Analyze or produce a scientific argument. • Design experiments, processes, or products. • Analyze a multi-step cause and effect relationship. • Perform a procedure having multiple steps and multiple decision points.

APPENDIX F: Glossary

A

analytical, observational study - a form of observational study used to answer a proposed question that, due to ethical considerations, does not allow for direct experimentation; these studies involve careful study design, which may include an extensive time period during which the observations occur with rigorous statistical control.

C

causal relationship - a relationship in which one variable causes another variable to occur, or to respond, in a consistent manner

claim - a declaration of truth about something; a “scientific” claim is one that is supported by empirical evidence.

computer simulation - a computer model that, when run, represents the behaviour of a system; computer simulations are used to study complex problems, such as global warming and population dynamics.

confounding variable - a variable, other than the independent variable, which may affect the dependent variable; this can lead to incorrect conclusions about the relationship between the independent and dependent variables; confounding variables are those that are to be *controlled* in an experiment.

correlation - a measure of the degree of association between two variables; correlations may be positive (an increase in one variable is associated with an increase in the other), negative (a decrease in one variable is associated with an increase in the other), or zero (a change in one variable is not associated with a change in the other); correlation between two variables does not imply causation; however, if a relationship is causal, it must also be correlational.

D

deductive reasoning - a form of reasoning that begins with a general statement and uses it to reach a logical, specific conclusion. In science, deductive reasoning is used when a hypothesis or theory is used to make a prediction, which is then tested by collecting evidence before accepting it as valid. Inductive reasoning, on the other hand, goes from specific observations to a generalized theory. Conclusions arrived at by deductive reasoning have a logical certainty that is lacking in those reached through inductive reasoning.

dependent variable - the variable that responds to changes made to the independent variable; in cause and effect relationships, the dependent variable or its response is the “effect” that is caused by the independent variable.

descriptive study - a form of observational study that is not directed by a question, but rather, involves collecting information that may lead to the development of a hypothesis

E

Earth and space science - Earth science explores the origins, physical features, and relationships between the atmosphere, land, and water systems on Earth; Earth science includes fields of study such as geology, meteorology, and oceanography; space science is interested in celestial bodies, space exploration, and how conditions in space affect scientific phenomena compared to conditions on Earth; cosmology, astronomy, and astrophysics are examples of specialized fields of study within space science.

effect - a response to change or a result produced by a cause

energy - the ability to do work or make things happen; potential energy or stored energy has the “potential” to make things happen; while energy cannot be seen, the affects of changes in energy can be detected.

F

falsifiable - describes the inherent possibility of being proven to be false or incorrect

feedback loop - describes a feature of systems in which an output of a component directly or indirectly influences the input of that same component, forming a loop in the chain of cause and effect; for example, in a population, the number of births affects the number of deaths, which in turn, affects the number of births; feedback can be positive or negative.

H

Hill’s postulates - a list of criteria used to describe the conditions necessary to classify a relationship between two variables as a cause and effect relationship; these criteria were developed in 1965 by Sir Austin Hill, an epidemiologist, to establish a causal relationship between smoking and a number of diseases.

hypothesis - a tentative explanation of what will happen in a particular situation under a given set of circumstances; hypotheses are not guesses but stem from problems, questions, observations, inferences, logic, other hypotheses, and background theory.

I

independent variable - the variable in an experiment that is manipulated by the experimenter; the cause of an effect

inductive reasoning - reasoning that goes from the specific to the general; in inductive reasoning, patterns observed in specific observations are used to make broad generalizations; these generalizations may or may not be true, since they lack the logical certainty of those arrived at by deductive reasoning; in science, these generalizations can be used to write hypotheses, which are then tested by deductive reasoning to see if they can be used to predict outcomes with any level of certainty.

infer - to interpret or explain an observation; inferences are based on personal experience, rather than testing.

iterative - describes a process that loops back on itself or has steps repeated, with each reiteration helping to further build upon an idea or understanding; both science and learning are iterative processes.

L

law - a descriptive generalization, often mathematical, that concerns the patterns of behaviour regarding some aspect of the natural world

life science - fields of study such as ecology, zoology, botany, cell biology, genetics, and biotechnology that examine aspects of living organisms and their environments

M

manipulative skills - collectively describes motor skills required for using labware, safety skills, and technical procedural skills required to perform experimental investigations

matter - the physical substance of which natural, living, and non-living things are made; matter has mass and occupies space; it can occur in many states such as liquid, solid, and gas.

model - a physical replica, conceptual diagram, mathematical equation, or simulation that helps us visualize or understand a complex concept, or the dynamics of a system

O

observational study - a scientific investigation that does not include direct manipulation and control of the variables by the experimenter; observational studies can be descriptive or analytical in nature and are common in medical research.

P

physical science - sciences concerned with matter, energy, and forces, and the relationships between them; chemistry and physics, and their specializations, are physical sciences.

pseudoscience - ideas that are not based upon testing hypotheses using scientific methodology, and do not generate interest in the scientific community, lead to new hypotheses, theories, discoveries, models, paradigms or worldviews.[30]

Q

qualitative data - data that is not numerical but describes qualities (e.g., colour, texture, odour, flavour) that are observed with the five senses

quantitative data - data that can be measured or quantified using numbers (e.g., temperature, density, mass, length, height)

R

randomized controlled study - a scientific investigation in which the samples to receive treatment are randomly selected to prevent bias and placed in one group called the *experimental group*; other samples that are to receive no standard treatment, or receive a replacement (such as a placebo) of the independent variable, are placed in the *control group*; all other variables are kept constant during the experiment for both groups; the experimental results from the two groups are compared to see if there are differences resulting from the treatment (i.e., caused by the independent variable); if the study is a *blind*, randomized, controlled study, the experimenter does not know which group received treatment, thus further minimizing bias.

S

scientific error - a measure of how far the result deviates from the expected result (i.e., how accurate it is) or how much the result varies when the experiment is repeated (i.e., how precise it is). Scientific errors can be *systematic*, resulting from poor design and the inability to control confounding variables, or from poorly calibrated equipment; other errors, *random errors,* result from limits in the precision of measuring equipment, limits in reading the device's scale, and fluctuations in conditions.

scientific study - scientific investigation or research

STEAM - a pedagogical approach that provides students with the opportunity to solve meaningful problems by integrating learning and skills associated with Science, Technology, Engineering, Art, and Math.

system - a collection of components (potential variables) that interact with one another so that the overall effect is much greater than that of the individual components; the boundaries of a system depend on the perspective of the observer.

system dynamics - the nonlinear behaviour of complex systems over time

systems thinking - an essential higher order thinking skill that involves thinking about a whole in terms of its parts, and alternatively, about the parts in terms of how they relate to one another in the whole; it involves analyzing the components, dynamics, and interactions within and between systems.

T

theory (scientific) - a well-substantiated explanation for a broad set of phenomena within the natural world; a theory synthesizes hypotheses, laws, principles, and facts from a broad range of studies and can involve a variety of fields.

V

variable - a factor that can change in an experiment; also used to describe a letter that represents an unknown number in a mathematical expression

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