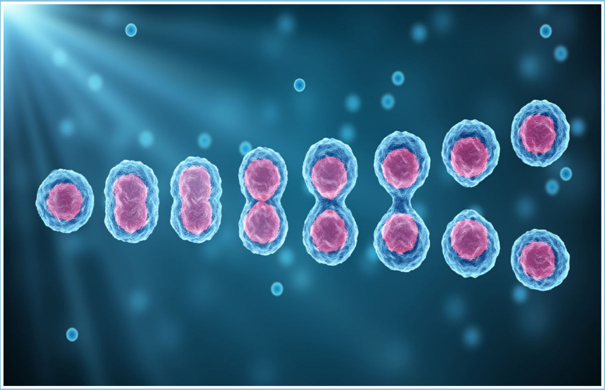
BIO621A

SCIENCE

Grade 12 Biology



Curriculum Guide
Pilot Draft

Prince Edward Island
CANADA

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Overview of Grade 12 Biology 621A

Course Description

Biology 621A provides an opportunity for students to develop scientific literacy by taking a journey through the study of cell division, reproduction, development, and genetics. Students then explore evolution and evolutionary mechanisms, culminating with an understanding of biodiversity. The specific topics studied in Biology 621A include:

- Mitosis and Meiosis
- Reproduction and Development
- Heredity
- Molecular Genetics
- Evolution
- Biodiversity

These topics, along with procedural knowledge, provide the content and skill framework that will engage students with the processes of scientific literacy (inquiry, problem solving, decision making) and continued development of the essential graduation competencies.

Forward

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). Sections of the Atlantic Canada Science 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

Introduction

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 inquire, problem solve, critically evaluate and make well-informed decisions, and maintain a sense of wonder about the world around them.

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.

Introduction

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; and
- being open-minded and projecting beyond the personal consequences of proposed actions.

Essential Graduation Competencies (EGC's)

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 and Lifelong Learning 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 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: 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*

Essential Graduation Competencies—Definitions

Critical Thinking

Learners are expected to analyse 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.

Learners are expected to

- use critical thinking skills to inquire, make decisions, and solve problems;
- recognize that critical thinking is purposeful;
- demonstrate curiosity, inquisitiveness, creativity, flexibility, persistence, open- and fair-mindedness, tolerance for ambiguity, and suspension of judgment;
- ask powerful questions which support inquiry, decision-making, and problem solving;
- acquire, interpret, and synthesize relevant and reliable information from a variety of sources;
- analyse and evaluate evidence, arguments, and ideas;
- use various types of evidence, reasoning, and strategies to draw conclusions, make decisions, and solve problems;
- reflect critically on thinking processes used and acknowledge assumptions;
- effectively communicate ideas, conclusions, decisions, and solutions; and
- value the ideas and contributions of others who hold diverse points of view.

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.

Learners are expected to

- recognize that technology encompasses a range of learning tools and contexts;
- use and interact with technology to create new knowledge;
- apply digital technology to gather, filter, organize, evaluate, use, adapt, create, and share information;
- select and use technology to impact and advance one another; and
- adopt, adapt, and apply technology efficiently, effectively, and productively.

Curriculum Design

Citizenship

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

Learners are expected to

- recognize the principles and actions of citizens in just, pluralistic, and democratic societies;
- demonstrate the disposition and skills necessary for effective citizenship;
- consider possible consequences of decisions, judgment, and solutions to problems;
- participate in civic activities that support and promote social and cultural diversity and cohesion;
- promote and protect human rights and equity;
- appreciate the complexity and interconnectedness of factors in analysing issues; and
- demonstrate understanding of sustainable development.

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.

Learners are expected to

- listen and interact purposefully and respectfully in formal and informal contexts;
- engage in constructive and critical dialogue;
- understand, interpret, and respond to thoughts, ideas, and emotions presented through multiple media forms;
- express ideas, information, learnings, perceptions, and feelings through multiple media forms, considering purpose and audience;
- assess the effectiveness of communication and critically reflect on intended purpose, audience, and choice of media; and
- analyse the impact of information and communication technology.

Curriculum Design

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.

Learners are expected to

- connect learning to personal and career development;
- demonstrate behaviours that contribute to the well-being of self and others;
- build healthy personal and work relationships;
- establish skills and habits to pursue physical, spiritual, mental, and emotional well-being;
- develop strategies to manage career balance and wellness;
- create and implement a personal, education, career, and financial plan to support transitions and achievement of personal, education, and career goals; and
- demonstrate preparedness to learn and work individually, cooperatively, and collaboratively in diverse, evolving environments.

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.

Learners are expected to

- gather information through all senses to imagine, create, and innovate;
- develop and apply creative abilities to communicate ideas, perceptions, and feelings;
- take responsible risk, accept critical feedback, reflect, and learn from trial and error;
- think divergently, and embrace complexity and ambiguity;
- recognize that creative processes are vital to innovation;
- use creation techniques to generate innovations;
- collaborate to create and innovate;
- critically reflect on creative and innovative works and processes; and
- value the contribution of creativity and innovation.

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 in the section "Foundations of Scientific Literacy" p.16. The foundations of science literacy support and are integrated with the six essential graduation competencies.

Figure 2. *Nature of Science*

General Curriculum Outcomes

General curriculum outcomes statements articulate what students are expected to know and be able to do upon completion of study in Science education.

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.

Curriculum Design

Specific Curriculum Outcomes

Specific curriculum outcomes (SCOs) identify what students are expected to know and be able to do for a particular course. 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 and the Essential Graduation Competencies.

SCOs will begin with the phrase—Learners are expected to… .

Achievement Indicators (AIs)

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. Taken together as a set, AIs support the SCO in defining specific levels of knowledge acquired, skills applied, or attitudes demonstrated by a student for that particular outcome.

It is important to note that AIs are not a prescriptive checklist to be taught in a sequential manner, are not a prioritized list of instructional activities, and are not a set of prescribed assessment items. Achievement indicators provide clarity and understanding to ensure instructional design is aligned to the SCO.

The set of achievement indicators for a given outcome begins with the phrase—Learners who have achieved this outcome should be able to… .

Elaborations

An elaboration provides a fuller description of the SCO and the instructional intent behind it. It provides a narrative for the SCO, gives background information where possible, and offers a broader context to help teachers gain a deeper understanding of the scope of the SCO. This may also include suggestions and/or reference supporting resources that may be helpful for instruction and assessment of the SCO.

Curriculum Design

Bloom's Taxonomy

Bloom's Taxonomy was published in 1956 as a framework for the purpose of classifying expectations for student learning as indicated by educational outcomes. David Krathwohl's 2002 revision of this taxonomy expands on the original work by defining the relationship between the cognitive process dimension—how we expect students to come to know and think about the outcome—and the knowledge dimension—the category of knowledge expressed by the outcome.

A full understanding of the relationship between the cognitive process and knowledge dimensions of Bloom's Taxonomy will serve students, teachers, and administrators by

- providing a framework for developing the specific curriculum outcomes (SCOs) for a particular course;
- identifying the type of knowledge and cognitive target of the outcome;
- providing a means for the alignment of specific curriculum outcomes with instructional activities and assessments; and
- providing a common language about the curriculum outcomes within all subjects to facilitate communication.

Cognitive Process Dimension

The cognitive process dimension classifies six types of cognition that learners may be expected to demonstrate or use as they work towards proficiency of any given specific curriculum outcome. The verb(s) that begins a specific curriculum outcome identifies the cognitive process dimension.

Table 1. Bloom's Taxonomy—Cognitive Process Dimension

Category	Description
Remembering	Retrieve, recall, and/or recognize specific information or knowledge from memory.
Understanding	Construct meaning from different sources and types of information, and explain ideas and concepts.
Applying	Implement or apply information to complete a task, carry out a procedure through executing or implementing knowledge.
Analysing	Break information into component parts and determine how the parts relate or interrelate to one another or to an overall structure or purpose.
Evaluating	Justify a decision or course of action, problem solve, or select materials and/or methods based on criteria and standards through checking and critiquing.
Creating	Form a coherent functional whole by skillfully combining elements together and generating new knowledge to guide the execution of the work.

Curriculum Design

SCO Structure

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

verb: explain
cognitive process: UNDERSTANDING

CK1.3 explain the processes involved in human reproduction and development.

Curriculum Guide Layout

The curriculum guide layout is designed to highlight the critical elements/features of the provincial curriculum required for a given course.

Table 2. Details of Curriculum Guide Layout

Feature	Description
Unit Name	Appears in the upper left hand corner.
SCO Block	Appears in the coloured box; contains the cognitive process level
AI List	Appears in the body of the page immediately following the SCO.
EGC Map	Appears at the bottom of the page.

Name of Curriculum Unit

Specific Curriculum Outcomes (SCOs)

Nature of Science

Specific curriculum outcome (SCO)

NoS 1	*Learners are expected to ...*
	evaluate the development and use of a technology related to Biology.

Remembering	Understanding	Applying	Analysing	Evaluating	Creating
				■	

Cognitive process level for this particular SCO

Achievement Indicators

Learners who have achieved this outcome should be able to ...

Set of achievement indicators (AIs)indicating “breadth and depth” of SCO

a analyse the design and function of a technology using scientific principles;

b describe examples where technologies were developed based on scientific understandings;

c analyse why and how a particular technology was developed and improved over time;

d analyse society's influence on scientific and technological endeavors;

e identify various constraints that result in trade-offs during the development of technologies; and

f explain how emerging technologies revolutionized thinking in the scientific community.

Essential Graduation Competencies Map

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

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Curriculum Design

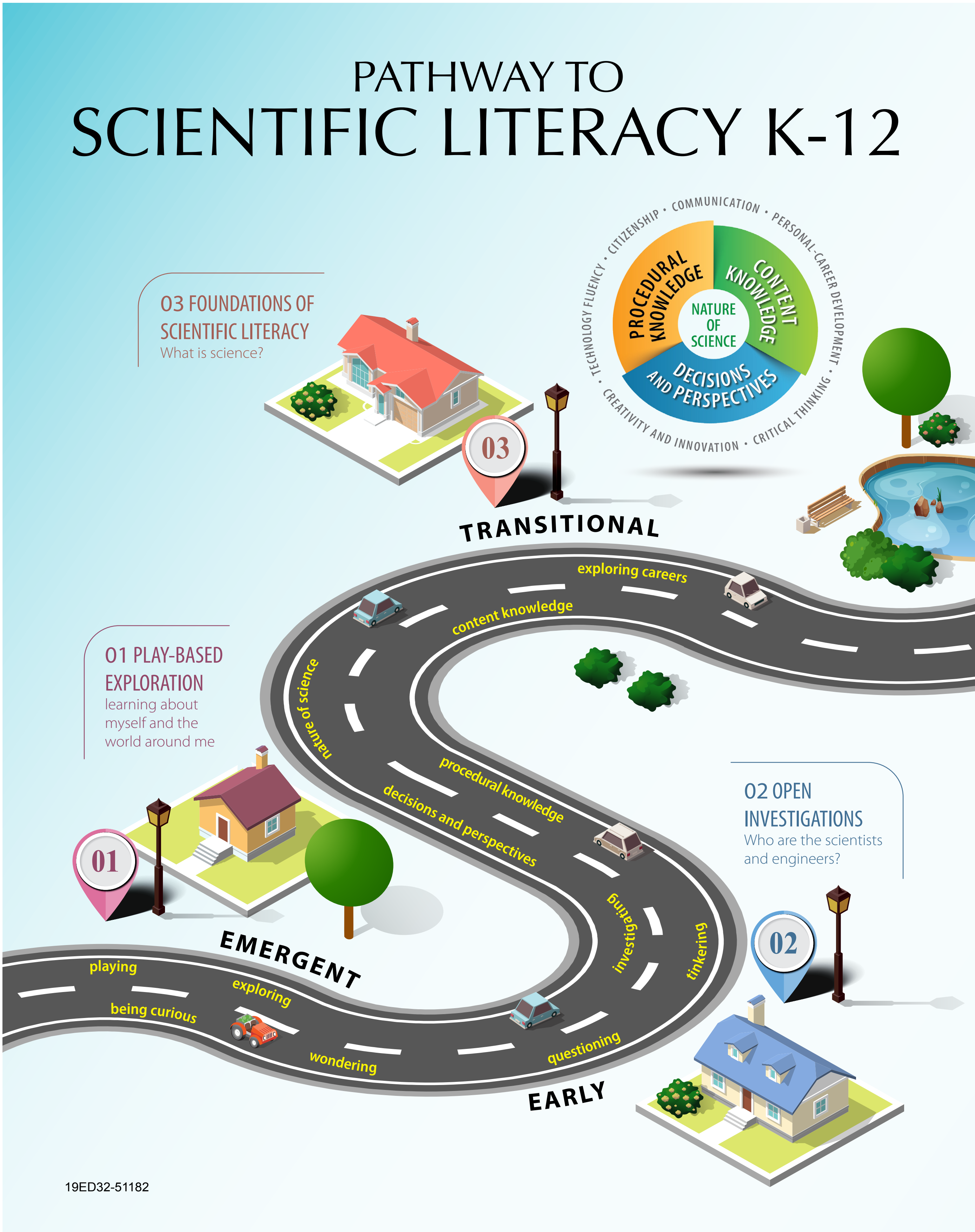
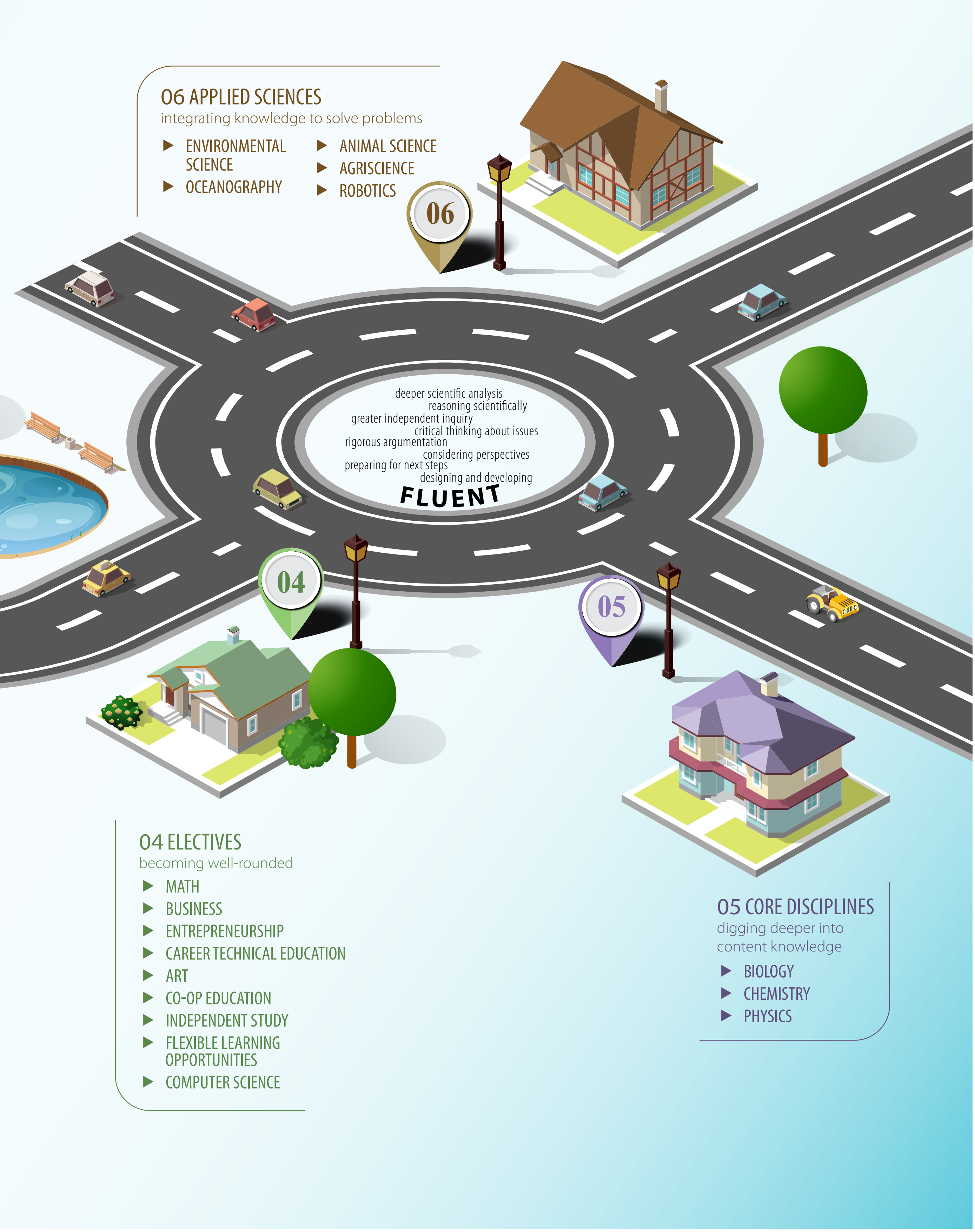


Figure 3. *Pathways to Scientific Literacy*

Pathway to Scientific Literacy



Overview

The four foundations of scientific literacy represent the complex and dynamic relationship of science and society that is depicted in Figure 4. 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.

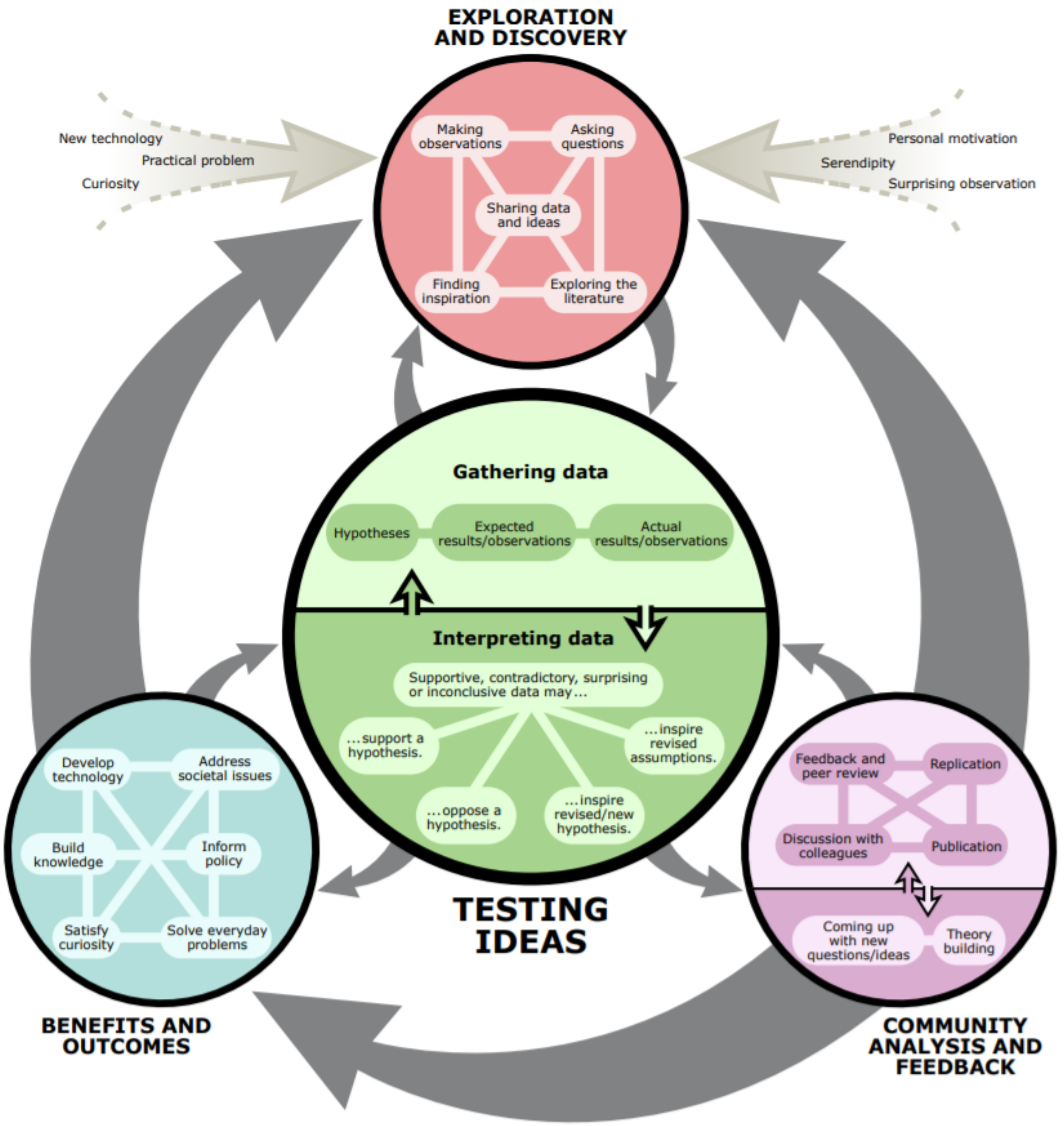


Figure 4. *How Science Works (University of California Museum of Paleontology 2016)*

Nature of Science

What is 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." (OECD 2015)*

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 come to know. Many ways of knowing have been identified—such as faith, intuition, emotion, perception, memory, imagination, and reason. (Dombrowski, Rotenberg, Brick 2013) 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.

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 6), 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 be analyzed and interpreted before it is considered evidence. The evidence used to support scientific claims may or may not result from experimentation. When evaluating evidence consider the following questions.

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

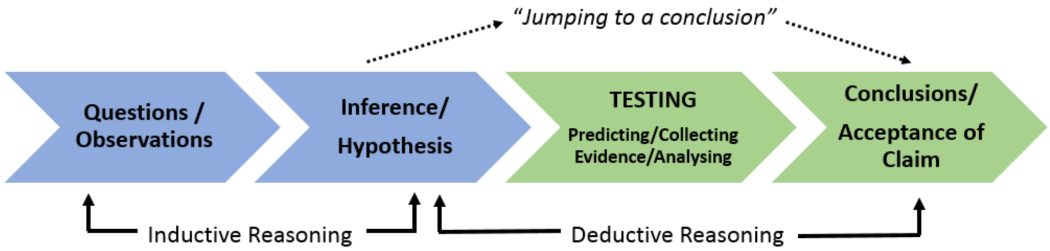


Figure 5. *Scientific Reasoning*

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."*
> *(Schick and Vaughn 2014)*

- 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 implied 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.

Examples of Theories

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

Procedural Knowledge

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.

Examples of No Relationship, Correlational, or Cause and Effect

- Smoking and cancer (Causal)
- Genetically modified organisms (GMOs) and decrease in biodiversity (no Relationship)
- Climate change and human activity (Complex Causal)
- Vaccines and autism (no Relationship)
- Megadoses of vitamins and health (Correlation)

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?

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. (Oleckno 2002) 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.

Questions to Help Determine 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?

Categories of Scientific Studies

One way to classify scientific inquiries is to divide them into two categories: experimental studies and observational studies (Figure 7). (Oleckno 2002) 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 inquiries, 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.

Modelling: Investigating Complex Systems

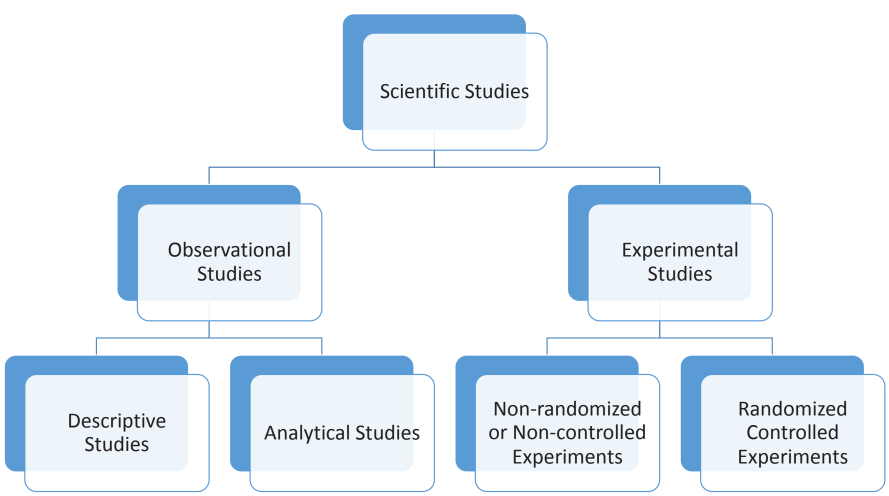


Figure 6. *Classification of Scientific Studies. Adapted from Oleckno, 2002*

Foundations of Scientific Literacy: Procedural Knowledge

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 (Figure 6) vary depending on the question being asked, the process of developing new scientific knowledge always involves a number of aspects or stages (Figure 7). 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 3).

Stages of Scientific Inquiry

Initiating and Planning
Performing and Recording
Analysing and Interpreting Data
Communicating Findings

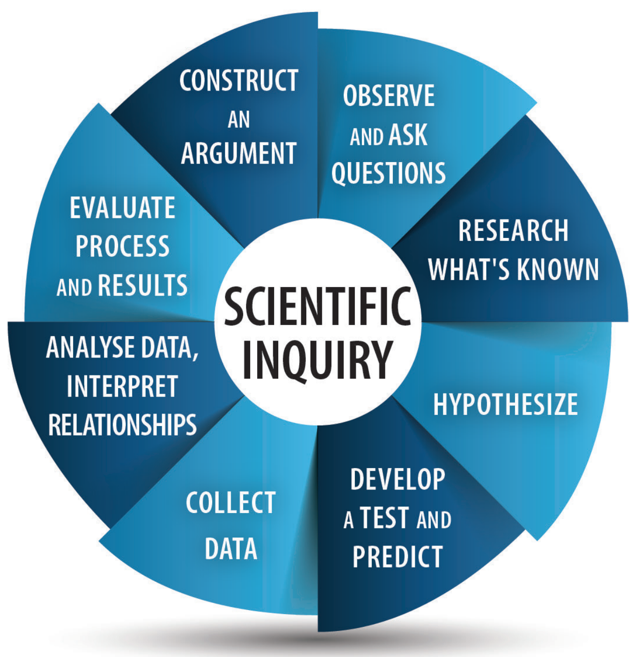


Figure 7. *Scientific Inquiry Process Wheel*

Foundations of Scientific Literacy: Procedural Knowledge

Table 3. Stages of the Scientific Inquiry Process and Selected Skills

Component of Scientific Literacy	Detail	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, control) 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 ↔ tables, diagrams ↔ 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

Foundations of Scientific Literacy: Procedural Knowledge

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." (Sterman 2000)*

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)*

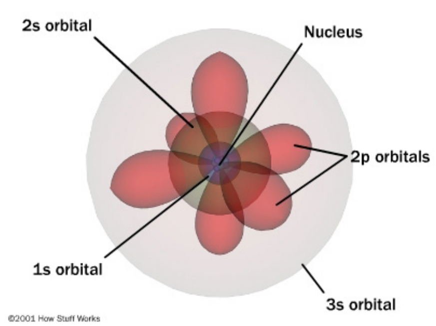


Figure 8. *Quantum Mechanical Model of the Atom*

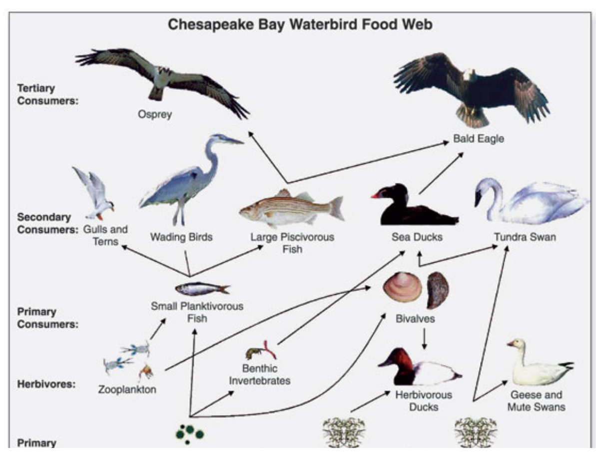


Figure 9. *Energy Flow in a Food Web (Perry 2019)*

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 (Wieman 2016)) 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.

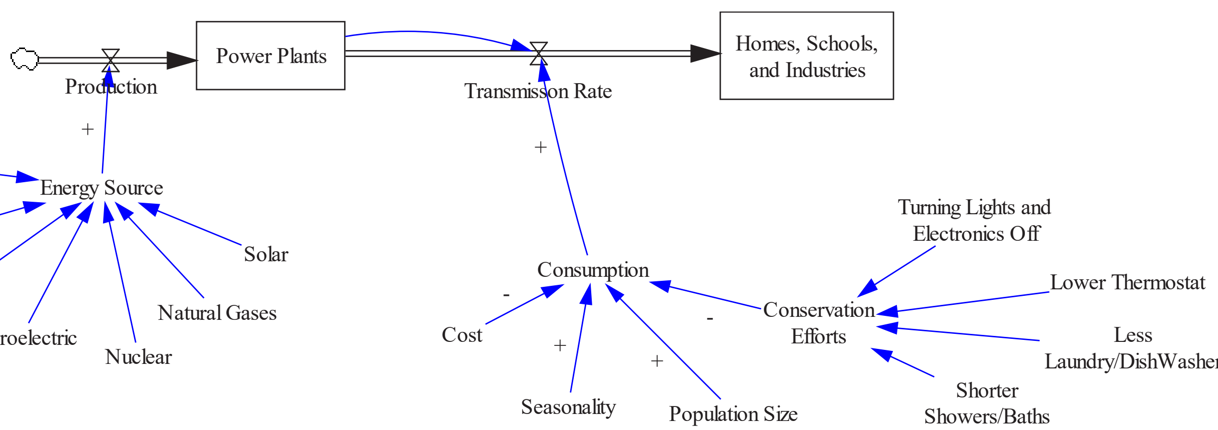


Figure 10. *Stock and Flow Conceptual Model*

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

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; 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.

Interdisciplinary Science Concepts

Matter
Patterns in Form and Function
Energy
Cause and Effect
Equilibrium, Stability, and Change within systems

Foundations of Scientific Literacy: Content Knowledge

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

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 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.

Foundations of Scientific Literacy: Content Knowledge

Cause and Effect

Cause and effect has been more thoroughly addressed in "Procedural Knowledge" p.20. 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 ("Modelling: Investigating Complex Systems" p.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.

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 enable 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 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. 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.

STEAM Problem-Solving Processes

The acronym STEAM represents Science, Technology, Engineering, Art, and Math. STEAM education is a pedagogical approach which provides students 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.

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 involves 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.

Table 4. STEAM Problem-solving

Problem-Solving Component	Science	Technology	Engineering	Arts	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

Considerations for Instruction

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. All are iterative processes that involve reflection, evaluation, and feedback throughout. All require analytical thinking and creative thinking. The figures below compare the problem-solving processes for science, engineering, art, and math.

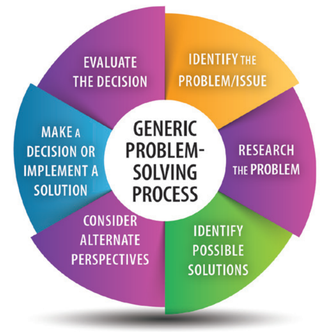


Figure 11. *Generic Problem-solving Process*

Figure 12. *Comparison of STEAM Problem-solving Processes*

Considerations for Instruction

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.

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

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.*

Considerations for Instruction

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.*

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.*

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.

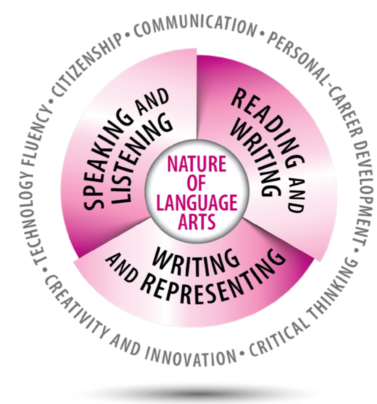


Figure 13. *The Nature of Language Arts*

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.

Considerations for Instruction

Instructional Strategies

> *"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." (National Research Council 2012)*

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.

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.

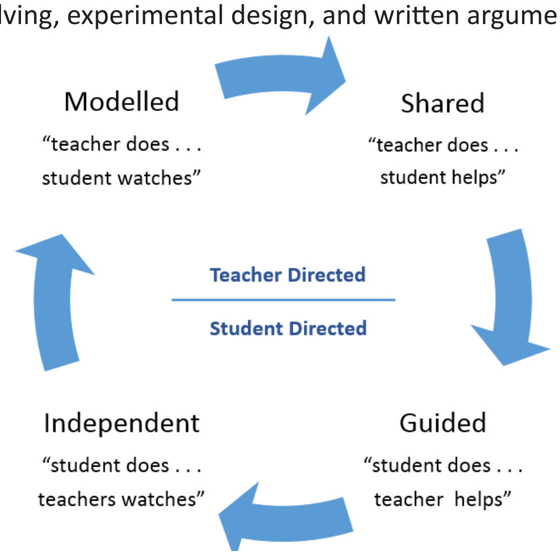


Figure 14. *Gradual Release of Responsibility*

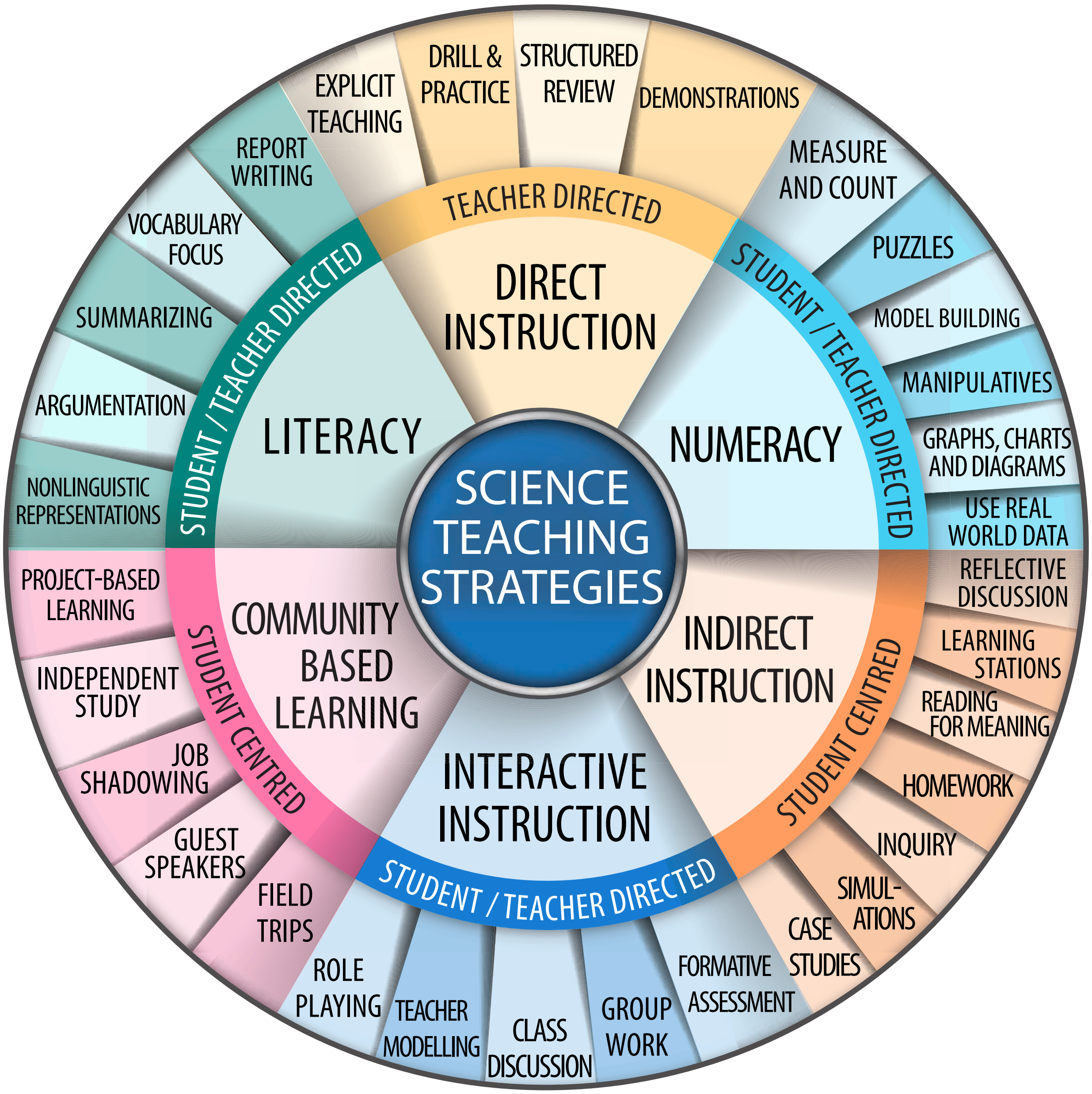


Figure 15. *Science Teaching Strategies*

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 ("Bloom's Taxonomy" p.10). 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.

Table 5. Science Assessment Strategies

Self/Peer Assessment	**Self/Peer Assessment**	**Observations/Conversations**	**Pencil Paper**
Formative	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

Biology 621A Course Overview

Outcome Summary

The outcomes of Biology 621A are categorized into four scientific literacy foundations (Nature of Science, Decisions and Perspectives, Procedural Knowledge and Content Knowledge). Table 6 below shows the summary of specific curriculum outcomes for Biology 621A.

Table 6. Summary of Curriculum Outcomes

GCO	Code	Specific Curriculum Outcome
Nature of Science; Decisions and Perspectives	NoS 1	evaluate the development and use of a technology related to Biology
	DP 1	construct arguments to support a decision or judgment, using examples and evidence and recognising various perspectives.
Procedural Knowledge	PK 1	apply knowledge and understanding of safe laboratory protocols and procedures.
	PK 2	apply appropriate techniques, procedures, and technologies for collecting and analysing data to solve problems.
	PK 3	use uncertainty in data measurement and data processing.
	PK 4	evaluate scientific phenomena using argumentation.
	PK 5	design an experiment identifying and controlling major variables
	PK6	use appropriate language, visual aids, and formatting conventions to effectively communicate plans, procedures, data, results, and conclusions of research and experimentation.
Content Knowledge	CK 1.1	describe in detail the process of mitosis and meiosis.
	CK 1.2	explain the processes involved in plant reproduction and development.
	CK 1.3	explain the processes involved in human reproduction and development.
	CK 2.1	analyse patterns of heredity.
	CK 2.2	analyse the structure, function, and synthesis of nucleic acids (DNA, RNA) and proteins.
	CK 2.3	analyse sources, types and effects of genetic variation.
	CK 3.1	describe historical and cultural contexts that have changed evolutionary concepts.
	CK 3.2	analyze evolutionary mechanisms and their effects on biodiversity.
	CK 3.3	explain the evolution of new species.
	CK 3.4	examine how the Hardy-Weinberg principle is used to determine whether a population is undergoing microevolution.
	CK 3.5	demonstrate an understanding of the fundamental principles of taxonomy.
	CK 3.6	describe the anatomy and physiology of organisms from each kingdom.
	CK 4	analyse the impact of infectious, genetic, and environmental diseases on the homeostasis of the system and the organism as a whole.

Assessment Framework

The assessment framework describes the relative weighting of each domain (unit or cluster of outcomes) within a specified course. It is constructed by transforming the depth and breadth of each specific curriculum outcome into an overall instructional time for each domain. The primary purpose of the assessment framework is one of validity - to align curriculum outcomes, instruction, and assessment. As such, the framework should be used to ensure that summative student assessments are representative of the instructional time and complexity of the specific curriculum outcomes for each domain, to inform the specified course reporting structure, and be consulted as a high-level guide for course planning, pacing, and syllabi development.

Table 7. Assessment Framework for BIO621A

Domain/GCO	Remember	Understand	Apply	Analyse	Evaluate	Create	GCO Weight
Nature of Science; Decisions and Perspectives					NoS1		**10%**
					DP1		
Procedural Knowledge			PK1				**30%**
			PK2				
			PK3				
					PK4		
						PK5	
			PK6				
Content Knowledge		CK1.1					**60%**
		CK1.2					
		CK1.3					
				CK2.1			
				CK2.2			
				CK2.3			
		CK3.1					
				CK3.2			
		CK3.3					
				CK3.4			
		CK3.5					
		CK3.6					
				CK4			

Reporting Structure

Nature of Science, Decisions & Perspectives	7	(10% of 70)
Procedural Knowledge	21	(30% of 70)
Content Knowledge	42	(60% of 70)
Major Assessments	30	(Reflective of Domain Weightings)

Nature of Science

NoS 1	*Learners are expected to ...*					
	evaluate the development and use of a technology related to Biology.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
					■	

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a analyse the design and function of a technology using scientific principles;

b describe examples where technologies were developed based on scientific understandings;

c analyse why and how a particular technology was developed and improved over time;

d analyse society's influence on scientific and technological endeavors;

e identify various constraints that result in trade-offs during the development of technologies; and

f explain how emerging technologies revolutionized thinking in the scientific community.

Essential Graduation Competencies

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

Elaborations

Technology can be defined as the practical application of knowledge. While many think of technology as being related to electronics or computing, the definition provided above suggests something far broader. Technology can be the development of surgical procedures (minimally invasive), drugs and vaccines (mRNA COVID vaccines), or equipment (magnetic imaging). Prior to engaging students in an assignment involving technology, it is important that that they have a sound understanding of what technology is.

Outcome NoS1 can be addressed independently, or in conjunction with complimentary outcome CK4. This outcome may be addressed via a project, either individually or in groups, where students present their research in the form of a “speakers series” or "video series" that is scheduled to occur throughout the course.

Students should analyse the design of their technology and the way it functions. To explain how their technology improved over time, students should look at historic iterations of their technology to identify improvements/efficiencies resulting from the evolution of scientific knowledge. Furthermore, emerging technologies may have revolutionized how the scientific community thinks about the technology production and/or use.

Examples of technologies related to select topics of Biology 621A are provided below as reference.

Cell Division
Students can investigate the role of biotechnology in cell growth and the potential it may hold for the regeneration of damaged tissues or parts of organisms. They may evaluate the role of cell division in the development of cancer and how knowledge of cell division might be applied to limiting cancerous growth in plants and animals. They may investigate the newer approaches to the chemical treatment of cancer, and the bases upon which they are effective. Other technologies to investigate include: stem cell research, cell transplant, spinal cord injury, therapeutic cloning, and reproductive cloning.

Reproductive Systems
Students could research and evaluate the uses and effects of estrogen/progesterone treatment on the health of women (including hormone therapy among menopausal women, and the use of birth control pills). They can evaluate technological solutions to human infertility, such as: artificial insemination; in vitro fertilization; in vitro maturation; surrogate motherhood; superovulation using fertility drugs; and embryo storage (cryopreservation). Furthermore, they can evaluate the design of birth control technologies/techniques and the ways they function. The following modes may be considered: a) barrier methods (condom, diaphragm, jellies and foams, IUD); b) hormonal methods (birth control pill, Norplant, morning after pill, Depo-Provera); c) surgical methods (tubal ligation, vasectomy)d); or other methods.

Embryonic Differentiation/Development
Students may evaluate how various technologies have improved the success rate of pregnancies and how this has led to new technologies. They may investigate the development of fetal surgery techniques to correct biological problems and evaluate techniques and technologies used to monitor various stages of embryonic or fetal development, such as: ultrasound; amniocentesis; fetoscopy; and CVS (chorionic villi sampling).

Genetics
Students could evaluate various technologies involved in detecting genetic disorders (amniocentesis, CVS - chorionic villi sampling, fetoscopy, genetic markers (linked marker and gene specific marker) and/or various technologies involved with treating genetic disorders (screening and prevention, surgery, environmental control, gene therapy). Furthermore, they can research new vaccine technology that uses mRNA instead of dead/weaken bacteria/virus or evaluate the technologies involved with the Human Genome Project or genome editing (e.g. CRISPR).

Evolution & Biodiversity
Students could explain modern techniques used in the classification process, including: radioactive dating; biochemical information (DNA/protein comparisons); structural information; comparative embryology; cellular structure; behaviour; and bioinformatics (DNA barcode database).

Decisions and Perspectives

DP 1	*Learners are expected to ...*					
	construct arguments to support a decision or judgment, using examples and evidence and recognising various perspectives.					
	Remembering	Understanding	Applying	Analysing	**Evaluating**	Creating
					■	

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a identify multiple perspectives that influence a science-related decision or issue;

b debate the merits of funding specific scientific or technological endeavours and not others;

c propose a course of action on social issues related to science and technology, taking into account an array of perspectives, including that of sustainability;

d distinguish between questions that can be answered by science and those that cannot, and between problems that can be solved by technology and those that cannot; and

e propose alternative solutions to a given practical problem, identify the potential strengths and weaknesses of each, and select one as the basis for a plan.

✓ Citizenship	✓ Critical Thinking	Personal-Career Development	**Essential Graduation Competencies**
✓ Communication	Technological Fluency	Creativity and Innovation	

Elaborations

This outcome is central to science as it touches all components of the nature of science—how and what we know about the natural/physical world. Argumentation is critical to science being a dynamic, evidence-based human endeavour that continuously involves the interplay between inductive and deductive reasoning.

Argumentation is evaluative in nature. It requires a deep understanding of the task that is being analyzed, followed by a decision (claim) to be made that is tied (reasoning) to supporting evidence. In the scientific realm, argumentation is often used in the discussion section of reports to justify the conclusion in relation to the experimental objective. In broader society, argumentation is informed by scientific knowledge used to make societal decisions that have moral, ethical, and cultural implications.

The intent of specific curriculum outcome DP1 is to engage students in argumentation involving questions that cannot be answered by science alone. Rather, science is used to inform many societal decisions. The following questions/scenarios provide contexts that may be used to engage students in specific curriculum outcome DP1. For more information on the process of constructing argument, please refer to specific curriculum outcome PK4 which addresses argumentation as it relates to evaluating scientific phenomena.

Examples of Biology 621A topics that could provide a context to address DP1 include:
Reproductive & Development
Students may debate the merits of funding solutions to human fertility problems versus the funding of human population control. They may investigate methods of population/birth control (e.g., China's one child per family rule; selection of one gender—usually male—and abortion of the other) in various countries around the globe, and assess the effects of these methods on the demographics of these countries.
Students could be divided into groups and asked to prepare an argument in support of or against one of the following statements:

- Doping tests should be mandatory for all professional and amateur athletes.
- A positive doping test should result in the lifetime ban of an athlete from his/her competitive sport.

Genetics & Biodiversity
Students could discuss the personal and ethical considerations increasingly faced by individuals as they consider the identification of genes, the possibility of prenatal diagnosis, and the ability to predict particular disorders. Questions such as the following could be considered:

- Would you want to know if you will suffer from a disabling disease later in life? Do you have a right to know?
- Do insurance companies have a right to accept/reject you for insurance coverage based on the results of voluntary and confidential genetic testing predicting your future health?
- Do employers have a right to know your genetic status as determined by voluntary genetic testing? For example, suppose you are a heterozygous carrier for sickle cell anemia. You know there is a belief within the airline industry that carriers are more sensitive to a decrease in cabin air pressure. Do you inform the airline of your genetic status before accepting a job? As genetic testing becomes more common, and more available, will potential employers have a right to know of your genetic status as a preliminary to hiring?

Students could analyse, from a variety of perspectives, the risks (e.g. privacy, financial, ethical) and benefits (e.g. knowledge of predisposition, analysis, prevention, treatment) to society of applying the scientific knowledge gained through the Human Genome Project
Students could investigate and perform a risk/benefit analysis and defend their position on situations such as:

- the risk and benefits of cloning from a biological, social, ethical, and environmental perspective.
- the use of genetically modified microorganisms (GMO) for drug production, pollution clean-up, environmental monitoring, and mining;
- the use of genetically modified food (GMF) in the marketplace (the extent to which genetic manipulation currently pervades the food industry, as in processed foods), and how aware or unaware the general public is of this;
- the importance of labelling genetically modified foods, and the practical issues involved.

Students could analyse examples of GMOs or GMFs, and their major significance. GMOs and GMFs to consider may include: herbicide-resistant plants; BST-producing bacteria; golden rice; transgenic salmon; insulin-producing bacteria; PCB-eating bacteria; and oil-eating bacteria.

Procedural Knowledge

PK 1	*Learners are expected to ...*					
	apply knowledge and understanding of safe laboratory protocols and procedures.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
			■			

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a interpret Workplace Hazardous Materials Information System 2015 (WHMIS 2015) pictograms and labels;

b ensure the safety of self and others by understanding the general safety protocols, procedures, and hazards;

c understand the safety protocols, procedures, and hazards specific to the activity being performed to ensure the safety of self and others; and

d apply appropriate protocols and procedures to acquire, use, and dispose of materials and equipment safely.

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

Elaborations

Students are expected to know their roles and responsibilities, the generic science safety guidelines, and the safety protocols and procedures specific to the science activity as outlined at the beginning of the activity.

Considering the importance of safety in science activities, assessment of this outcome should be frequent and triangulated (observation, conversation, product). This outcome contains a blend of knowing and doing; consequently, assessment should incorporate a variety of assessment techniques, some of which must incorporate performance assessment where students can demonstrate their knowledge and understanding through application.

Prior to engaging in laboratory activities, students should be provided with generic science safety guidelines. These guidelines can be introduced in a variety of creative ways to encourage thoughtful discussion. Students could engage in co-construction of criteria to relate to the questions, "What matters, what counts, and what is important for a safer science laboratory?" To assist with this process, a series of questions can be created to catalyse student thoughts on the various aspects of safety in the science laboratory. Furthermore, safety concerns and procedures specific to an activity should be addressed at the beginning of each activity.

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 Labeling of Chemicals (GHS), which is a world-wide system currently being used. Information regarding WHMIS 2015 and GHS can be found on the website for the Canadian Centre for Occupational Health and Safety (http://www.ccohs.ca).

In grade 9 and 10 science (SCI9, SCI421A), students were introduced to the Workplace Hazardous Materials Information System (WHMIS 2015) through the expectation of applying safe practices when handling and disposing of lab materials. This required that students would recognise the components of workplace and supplier labels, and safety pictograms, and follow the safety advice provided. The intent of indicator PK1a is to have students interpret WHMIS labels and pictograms when the opportunity arises to do so.

Procedural Knowledge

PK 2	*Learners are expected to ...*					
	apply appropriate techniques, procedures, and technologies for collecting and analysing data to solve problems.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
			■			

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a use appropriate techniques for observation, data collection, and analysis;

b use appropriate data collection tools, including data loggers, for data collection;

c use appropriate data analysis tools, including spreadsheets, for data analysis; and

d communicate appropriate techniques and procedures needed to investigate scientific phenomena and solve a problem.

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

Elaborations

It is important that students not only know how to use technologies (ex. microscope, data logger, scalpel, spreadsheet) and techniques (ex. observation, sampling, analysis, anatomical dissection) that are common to science, but are also able to apply and communicate appropriate techniques, procedures, and technologies specific to the topic being investigated in order to solve problems. Students must attain a level of understanding that allows them to act flexibly with the procedural knowledge that they acquire.

The tools, techniques, and procedures expected of students are those found and performed in the common core laboratory activities identified below.

Common Core Laboratory:

Lab 1: Observing Mitosis and Meiosis
Lab 2: Flower Dissection / Angiosperm Reproduction
Lab 3: Virtual Fruit Fly Experiment
Lab 4: Applying the Hardy-Weinberg Equation
Lab 5: Sampling Pond Organisms
Lab 6: Creating/Using a Dichotomous Key
Lab 7: Group Dissection - Major Animal Phyla (Arthropod, Mollusk, 6 vertebrate)

The depth of this outcome goes beyond understanding and use. Students are expected to apply (and communicate) the techniques and procedures used. Consequently, the following question related to a common core lab procedure further elucidates the expectation for assessment of outcome PK 2.

Question
Select an autosomal dominant trait with a readily recognizable phenotype. Assuming the school population meets the conditions of Hardy-Weinberg equilibrium, explain how you would determine the quantity of the population that is homozygous dominant.

Answer Details
It is expected that the students would identify/determine the:
- population size;
- phenotype distribution (with/without trait);
- phenotype frequency;
- genotype frequency “q2”(q2 frequency = homozygous recessive phenotype frequency);
- allele frequency “q”;
- allele frequency “p”; and
- genotype frequency “p2” and population of homozygous dominant.

Please note: For efficiency purposes, outcome PK 5 may be addressed by incorporating experimental design in any of the common core laboratories identified above.

Procedural Knowledge

PK 3	Learners are expected to ...					
	use uncertainty in data measurement and data processing.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a understand random and systematic error and recognise their sources;

b distinguish between accuracy and precision;

c identify the error associated with measured values (± or % range);

d identify quantities, both implicit and explicit, required to solve a problem;

e manipulate subject-specific algebraic expressions to isolate any variable; and

f estimate and calculate an unknown quantity using known quantities.

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

Elaborations

Students should understand that uncertainty exists with all measured quantities, and the sources of error fall into one of two categories: random or systematic. Students should be able to identify sources of random and systematic error in laboratory experiments.

Random error results from the imprecision of measuring devices and leads to values measuring above or below the expected value. We often run multiple trials or use more precise equipment to mitigate random error.

Systematic error results from improper experimental setup and leads to values measuring always above or always below the expected value. Examples of systematic error would be a poorly calibrated instrument or a poorly controlled experiment. Multiple trials will not mitigate systematic error.

Evaluating the extent of scientific errors is important, since errors directly impact the quality of evidence used to support the final conclusion. Students should look for scientific errors that affect accuracy and precision. Scientific errors are accepted as an inherent part of science and reported with the results. Students should realize that scientific errors differ from mistakes. Mistakes include such things as forgetting to record data, miscalculating, spilling material, and setting up an apparatus incorrectly. In good science practice, investigations in which mistakes have occurred are discarded.

Table 8. Types of Error

Type of Error	Characteristics	Sources of Error	Ways to Reduce
Systematic Error (inaccuracy)	• consistently in one direction • due to design or skill • can be eliminated	• quality of equipment • uncalibrated equipment • failure to control variables • bias (observational)	• improve design or equipment • use a control or blind study • calibrate equipment
Random Error (imprecision)	• fluctuates randomly • can be reduced but not eliminated	• normal fluctuation in measurements • imprecision of instruments used to measure • too few measurements or samples	• use more precise equipment • increase number of trials • increase number of samples

Accuracy and precision are often used interchangeably; however, in science they have very specific meanings. Students should understand accuracy as how close a measured value is to the expected value, whereas precision relates to how close measured values are to each other. Specifically, precision dictates the significant figures in a measured value and is represented by uncertainty values, either as absolute or percent uncertainty.

Students should identify and record the absolute/percentage uncertainty that is associated with the use of equipment for measurements when the uncertainty is provided with the equipment (e.g., temperature probe uncertainty ± 0.1 °C). Having these values will be of assistance to students when engaged in writing discussion/conclusions for laboratory experiments (links to PK 4). While the determination of uncertainty using various least count methods is a requirement in 500/600-level physical science courses, it is not an expectation that students in Biology engage in the determination of uncertainty.

Procedural Knowledge

PK 4	*Learners are expected to ...*					
	evaluate scientific phenomena using argumentation.					
	Remembering	Understanding	Applying	Analysing	**Evaluating**	Creating
					■	

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a understand that scientific argumentation involves claim, evidence, and reasoning;

b support a claim using evidence from experimental data and associated reasoning;

c support a claim using concepts, models, laws, or theories and associated reasoning;

d argue the directional impact of error on results;

e argue which sources of error most likely had major/minor effects on results;

f explain ways to adjust experimental procedure to mitigate uncertainty or to use controls to strengthen claims; and

g evaluate the limitations of the evidence provided, including weaknesses in the methodology and possible sources of bias.

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

Elaborations

This outcome is central to science, as it touches on all components of the nature of science — how and what we know about the natural/physical world. Argumentation is integal to science being a dynamic, evidence-based human endeavour that continuously toys with the interplay between inductive and deductive reasoning.

Argumentation is evaluative in nature. It requires a deep understanding of the task that is being analysed, followed by a decision (claim) to be made that is tied (reasoning) to supporting evidence. Argumentation is often used in the discussion section of reports to justify the conclusion in relation to the experimental objective. Furthermore, scientific argument is used to explain the types of error in experimentation, their directional impact on results, and resulting limitations of the study.

Argumentation has been introduced to students in earlier science courses, and it has a close correlation to other subject areas that involve persuasive writing and formal debate. The components of scientific argument (claim-evidence-reasoning), and the skill of writing argument should be formally addressed. The use of exemplars and gradual release of responsibility for learning ("Instructional Strategies," p.34) are recommended as instructional strategies. Writing frames such as the one illustrated below can be used to organize evidence and explanation as they relate to the claim. Students could be asked to complete a writing frame by deconstructing an exemplar. This process should elucidate how a writing frame is used and how to move from the frame to the completed argument.

Table 9. Claim, Reasoning, and Evidence Writing Frame Sample

Claim	Reasoning	Evidence
Your answer to a given question is your claim.	Reasoning is the bridge between your answer (claim) and the data that led you there (evidence).	The data (evidence) that helped you arrive at your claim is your evidence.
In the space provided, state your claim, define your evidence, and indicate how and/or why your evidence supports or justifies your claim. Together, your claim, evidence, and reasoning form your evidence-based argument.		

Procedural Knowledge

PK 5	*Learners are expected to ...*					
	design an experiment identifying and controlling major variables.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
						■

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a formulate relevant questions to investigate;

b formulate hypotheses and make informed predictions;

c identify and control major variables;

d select appropriate procedures/techniques to vary the independent variable; and

e select appropriate sampling procedures/techniques for the dependent variable.

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

Elaborations

Students are expected to continue the practice of experimental design that was developed in prior science courses (see below). Although the practice and understanding of experimental design is relatively static, the scientific phenomena studied in 500/600-level courses are more complex from a content and procedural knowledge perspective as compared with earlier grades. Consequently, the depth of knowledge required to design an experiment in 500/600-level courses will inherently be more complex as well.

Depending on the phenomenon being studied, teachers can decide if students will engage in designing an entire experimental procedure or modifying the design of a component of a study. For example, an experimental procedure may have already been used by students to study the phenotypes of offspring of fruit flies in order to determine if a trait is autosomal or sex-link. In consideration of the procedure used, the students can decide on a question they wish to investigate and then modify the original procedure to allow for an investigation pertaining to the new inquiry. Alternatively, students could be asked to examine an experimental procedure and recommend modifications that would mitigate the effects of confounding variables that may have been originally overlooked.

During intermediate grades, students were introduced to experimental design and practised generating descriptive and causal questions, identifying variables, writing and testing hypotheses, and identifying scientific errors (specifically, bias and lack of control of variables). In addition to designing an investigation, students in Science 421A were expected to analyse and evaluate the design of experiments more deeply. Criteria used to evaluate science investigations include reproducibility, repeatability, reliability, accuracy, and precision.

Throughout their studies of science, students should have been formally introduced to the following terms used in experimental design and would have be made aware that a fundamental principle of science is that results produced by an investigation are repeatable and reproducible.

Repeatable	yields consistent (reliable) results when performed by the same individual using the same equipment or apparatus
Reproducible	yields consistent (reliable) results when performed by another investigator using the same equipment or apparatus
Independent Variable	manipulated (altered) variable that causes a change in another variable. This is the only variable to be manipulated by the experimenter.
Dependent Variable	responding (measured) variable that is affected by the independent variable. The experimenter observes or measures any changes that occur.
Controlled Variable	variable that is neither altered nor measured, rather is maintained constant. To be certain that the independent variable is causing the observed effect on the dependent variable, all other variables must be controlled or kept constant.
Confounding variable	variable that is not properly controlled and can inadvertently affect the results
Hypothesis	a tentative, testable explanation to answer a causal question. It is a misconception that hypotheses are guesses. A hypothesis is accompanied by a prediction statement.
Prediction	statement describing what is expected to happen during the test if the hypothesis is correct. The prediction statement includes the direction of change (e.g., increase or decrease).

Procedural Knowledge

PK 6	*Learners are expected to ...*					
	use appropriate language, visual aids, and formatting conventions to effectively communicate plans, procedures, data, results, and conclusions of research and experimentation.					
	Remembering	Understanding	**Applying**	Analysing	Evaluating	Creating

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a use appropriate language conventions and visual aids to effectively communicate in research papers and experimental reports;

b use appropriate numeric and symbolic modes of representation to report data and associated units of measure;

c use a consistent style guide (MLA, APA, ACS, APS, Chicago, etc.) for referencing the works of others; and

d use a consistent style guide (MLA, APA, ACS, APS, Chicago, etc.) for formatting research papers and experiment reports and their components (tables, charts, lists, graphs, etc.).

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

Elaborations

The organization and style of scientific writing emphasize clarity, objectivity, and the use of specialized technical language to ensure that the message communicated is clear and unambiguous. Implied in “effectively communicate” in PK 6 is the quality or clarity of writing based on criteria such as word choice, organization, fluency, and mechanics.

To develop proficiency with technical writing, students can be provided with opportunities to practise skills specific to individual sections of lab reports (e.g., writing a sequential procedure, recording observations, interpreting patterns and trends in graphed data, and formulating a discussion) before completing a whole report.

Students should demonstrate proficiency using informational text features and technical writing conventions by creating purposeful tables, graphs, models, and diagrams. Students should also clearly communicate the nature of relationships within data, devices, apparatuses, or scientific concepts.

For consistency and clarity of expectations, a particular style guide should be adopted by your science department and applied across all science courses. Once students become proficient in applying the detail necessary to adhere to a particular style, they should have little difficulty applying alternate styles to written work. As multiple style guides are employed between, and within, each science discipline, it is important to note that the consistent use of a style guide is important. The type of style is of nominal importance. The same style guide should be further used to explicitly teach students how to avoid plagiarizing the work of others.

The use of exemplars and gradual release of responsibility for learning ("examine how the Hardy-Weinberg principle is used to determine whether a population is undergoing microevolution." p.74) to elucidate appropriate language and style conventions are recommended as instructional strategies.

Content Knowledge

CK 1.1	*Learners are expected to ...*					
	describe in detail the process of mitosis and meiosis.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
		■				

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a describe the cell cycle and understand the significance of interphase in relation to cell division;

b identify and describe the role of the organelles involved in cell division (e.g., microtubules/spindle fibers, centrioles/centromere);

c describe the significant events of the four stages of mitosis, followed by cytokinesis;

d explain the importance of maintaining a constant number of chromosomes via mitosis;

e describe the significant events which occur in the eight stages of meiosis;

f explain the necessity of chromosome reduction during the production of sex cells;

g explain the importance of crossing over and independent assortment and their influence in creating diversity in sex cells;

h describe ploidy and explain the difference between haploid and diploid cells and connect to its relevance in cell division; and

i apply their understanding of meiosis more specifically to the processes of spermatogenesis and oogenesis and compare key differences between them (related to SCO CK1.3).

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

Elaborations

Classroom or laboratory simulations of the process of mitosis and meiosis may be useful. Students may use pipe cleaners to simulate chromosomes and follow the process by preparing pipe cleaner models of chromosomes during each stage in these processes. Furthermore, these processes can be annotated or animated using available software. Crossing over (chiasma) and independent assortment in meiosis can also be illustrated through a pipe cleaner (colored) activity. This provides the students with a visual confirmation of the exchange of genetic information and its effect on randomizing gene combinations within the chromosomes. (Links to Biodiversity and Genetics)

Students should be given the opportunity to observe and investigate the stages of the cell cycle and cytokinesis within both plant and animal cells through laboratory or computer simulations, diagrams, photographs, or time lapse video technology. Stages of mitosis can be observed using prepared slides of plant cells (e.g., onion root tips)or animal cells (e.g., whitefish blastula). Some comparisons between the processes of mitosis in plant and animal cells may be made by careful examination of these prepared slides. Students may be asked to identify,sketch, and discuss what is occurring during each of the stages. Use of a video microscope display can assist the teacher in initially illustrating, as a class activity, how to distinguish between cells in each of the different stages. Videos and animations to show mitosis and meiosis are effective and are easily located.

Background leading up to this topic should include the concept of chromatin and the state that chromosomes can be found (single vs. double-stranded). The Focus is on animal cells and it should be acknowledged that there are slight differences in plant cells. Teachers should reiterate that there is no replication of DNA between Meiosis I and II. Teachers should highlight the fact that Meiosis II will only occur in Oogenesis if fertilization occurs (links to SCO CK1.3).

Content Knowledge

CK 1.2	*Learners are expected to ...*					
	explain the processes involved in plant reproduction and development.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
		■				

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a distinguish between asexual and sexual reproduction;

b explain the various types of asexual reproduction;

c explain the function of the basic structures involved with sexual reproduction in angiosperms (flowering plants); and

d describe the process of sexual reproduction in flowering plants.

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

Elaborations

Teachers may want to address achievement indicators C & D in conjunction with specific curriculum outcome CK 3.6 (Evolution, Change, and Biodiversity).

Investigation of the range of reproduction found within the plant kingdom serves to reinforce the concept of biodiversity studied in this course. There are a variety of ways in which students can compile and present information about reproductive strategies, such as the use of charts, tables, or diagrams.

The types of assexual reproduction in plants to address include: budding, binary fission, spore production, fragmentation, and parthenogenesis.

The structures of sexual reproduction in angiosperms that should be identified include: pistil, stamen, pollen, ovules, seed, and fruit. The description of the process of sexual reproduction in flowering plants should be taken from the production of pollen to the production of a seed. This should include pollen tube formation and the process of one sperm nucleus (n) uniting with the egg (n) to produce a diploid zygote (2n); and the basic role of endosperm in embryo development.

Content Knowledge

CK 1.3	*Learners are expected to ...*					
	explain the processes involved in human reproduction and development.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
		■				

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a explain the structure and function of the human male reproductive system;

b describe the role of hormones in the regulation of the human male reproductive cycle;

c explain the structure and function of the human female reproductive system;

d describe the role of hormones in regulation of the human female reproductive cycle;

e explain the processes of fertilization in human reproduction;

f explain the processes of development in human reproduction

g describe the basic stages of embryonic development - cleavage, morula, blastula (blastocyst), gastrula (3 primary germ layers), neurula, fetus;

h describe the functions of primary membranes during the embryonic development of animals (yolk, allantois, amnion, chorion) and resulting tissues (placenta); and

i explain the processes of development and birth in human reproduction, including the role of oxytocin as an exampke of a positive feedback loop.

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

Elaborations

Students should be provided with the opportunity to observe and discuss the functions of the principal features of the male and female reproductive system - using models, dissections, or computer simulations - and to identify and label the major structures in drawings or photos of that organ system. Male structures include: testis, scrotum, seminiferous tubules, epididymis, sperm duct (vas deferens), Cowper's (bulbourethral) gland, seminal vesicle, prostate, and urethra. Female structures include: ovary, follicles, oviduct (Fallopian tube), fimbriae, uterus, endometrium, cervix, and vagina.

Students should identify and state the functions of the principal reproductive hormones in the male and female reproductive system and explain their interactions in maintaining the male reproductive system, and the female menstrual cycle, respectively. Male hormones include: inhibin, follicle stimulating hormone (FSH), luteinizing hormone (LH), and testosterone. Female hormone include: estrogen, progesterone, luteinizing hormone (LH), follicle stimulating hormone (FSH).

Students are expected to trace the journey of sperm and egg from their origin until fertilization and implantation. They could be provided with available websites that animate the journey of sperm and/or egg from their origin until fertilization and implantation. Give examples of tissues that the germ layers develop into. Explain the structure and role of the placenta in later development. Similarly, students could be asked to animate this process with available software.

Teachers should describe the cause of multiple births, including fraternal and identical twins.

Students should have the opportunity to observe the stages of embryo development - preserved materials, prepared slides (e.g., cleavage of sea stars), audiovisual presentations, or computer simulations - and extrapolate from these events to the development of the human fetus. In addition, there are good websites available on the Internet that illustrate the process of development.

Students should be aware of the physiological events that occur during and after the process of childbirth (cervical dilation, loosening of pelvic ligaments, rupture of the amniotic membrane, uterine contractions, delivery of fetus, and expulsion of the placenta) and the role of hormonal control associated with implantation, birth, and lactation (progesterone, estrogen, oxytocin, prolactin, human chorionic gonadotropin (HCG).

This outcome should be addressed in conjunction with outcomes NoS 1 and CK 4. Students should explore the potential health risks associated with exposure to sexually transmitted infections (STIs) and substance abuse, including teratogens. It is important for students to not only consider immediate health concerns but also the broader societal impacts, such as the effects on future children and healthcare systems. See the NoS1 and CK4 elaboration pages for specific examples related to reproductive systems and embryonic differentiation/development.

Content Knowledge

CK 2.1	*Learners are expected to ...*					
	analyse patterns of heredity.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
				■		

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a describe Mendel's contribution to the understanding of the basis of heredity;

b Explain how Mendel's experiments support the (i) principle of dominance, (ii) law of segregation, and (iii) law of independent assortment;

c Explain the chromosomal theory of inheritance;

d explain the meaning of the relevant terms: heredity, genetics, trait, P generation (parent generation), F1 and F2 generation(first and second filial generation), hybrid, purebred, dihybrid, monohybrid, dominant, recessive, gene, allele, homozygous, heterozygous, product rule, Punnett square, genotype, and phenotype;

e predict the outcome of monohybrid and dihybrid crosses, including incomplete and co-dominance;

f explain the significance of a test cross and use a test cross to determine the unknown genotype of a dominant organism;

g explain the meaning of the terms: (i) incomplete dominance (ii) co-dominance (iii) multiple alleles;

h analyse the inheritance of traits governed by multiple alleles by predicting the genotypic and phenotypic ratios in crosses involving human blood types (ABO groups);

i define sex-linkage and explain why sex-linked defects are more common in males than females;

j distinguish between genotypes and phenotypes evident in autosomal and sex-linked inheritance;

k predict the outcome of monohybrid and dihybrid crosses involving sex-linked traits;

l explain the influence of polygenic traits on inheritance patterns; and

m analyse and interpret the patterns of inheritance shown on pedigree charts.

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

Elaborations

As an introduction to this unit of study, students may be asked to investigate their own individual dominance/recessiveness as related to visual/sensory traits (e.g., widow's peak, dimples, tongue rolling, attached/free ear lobe, the ability/lack of ability to taste PTC). Data from a class activity of this nature can be collected and the prevalence of dominant and recessive traits within this restricted population can be compared to prevalence in the population in general. Activities can be performed that simulate the chance formation and pairing of gametes (e.g., simulate Mendel's experiments, substituting the tossing of coins and heads/tails for plant characteristics). Students can investigate visually the phenotypic ratios evident during a laboratory activity using artificially pollinated ears of genetic corn. Genotypes of the parent ears can be determined and the expected phenotypic ratios predicted.

The concepts of incomplete dominance and co-dominance are very similar with respect to phenotypic expression. Co-dominance is the condition in which both alleles of a gene are expressed. Examples include roan cattle/horses (red and white hair) and barred-plumage chickens (black and white feathers). Incomplete dominance is inheritance in which an active allele does not entirely compensate for an inactive allele. Examples Include snapdragon flowers (heterozygous is pink) and Japanese four-o'clock flowers (heterozygous is pink).

There are a number of different methods of representing the alleles for incomplete and co-dominance. For example, in incomplete dominance for flower colour in snapdragons the following can be used:
(i) R - red; R' - white
(ii) R - red; W - white
For co-dominance, blood type should be represented using the following alleles: (I^A, I^B and i)

Students should be able to solve dihybrid crosses involving one trait that is completely dominant with one other trait that is not (co-dominance,incomplete dominance, multiple alleles). Teachers should use multiple resources to find genetic problems of this type. Multiple alleles should be explained with reference to blood types. Students could explore other examples of multiple alleles such as eye colour in Drosophila.

It is impossible to determine simply by its appearance the genotype of an organism that is expressing the dominant trait. In order to introduce the idea of test cross, teachers should pose the question, "How would you determine the unknown genotype?" Teachers should note that the absence of the homozygous recessive trait in the offspring does not confirm that the unknown parent is homozygous dominant, especially in small samples of offspring.

It is important to note that many human traits do not follow basic patterns of inheritance. For instance, skin and eye color or height can be used to illustrate and explain inheritance patterns for polygenic traits. It is not the intent for students to perform an analysis of patterns of inheritance involving polygenic traits.

Students should draw and interpret pedigree charts from data on human single and multiple allele inheritance patterns. They should be able to analyse inheritance data and infer the method of inheritance(e.g., dominant, recessive, sex-linked). They should compare pedigree charts for the inheritance of non sex-linked and sex-linked conditions (The pedigree of the hemophilia in Queen Victoria's bloodline is readily available and serves to provide a biological/historical cross-curricular link.). Student groups may design procedures, collect data, and prepare family pedigrees to demonstrate the inheritance of autosomal traits determined by single and multiple alleles, and sex-linked traits. Simulations of forensic investigations or murder mysteries involving clues based on genetic traits (e.g., blood type, freckles) and pedigree information that require students to "solve" a crime based on the information provided are interesting ways to enhance student knowledge and interest in genetic analysis.

Content Knowledge

CK 2.2	*Learners are expected to …*					
	analyse the structure, function, and synthesis of nucleic acids (DNA, RNA) and proteins.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
				■		

Achievement Indicators

Learners who have achieved this outcome should be able to …

a describe various incremental contributions to our current understanding of DNA's role as the hereditary molecule;

b describe nucleotide, RNA, and DNA structures, acknowledging the contributions of Franklin, Watson, and Crick;

c compare and contrast the features of DNA and RNA;

d examine and describe the role of RNA/DNA and enzymes used in the semi conservative model of DNA replication;

e analyse the "central dogma" of gene expression - the basic role of DNA/RNA/amino acids in protein synthesis; and

f explain triggers (hormonal, environmental) for gene expression.

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

Elaborations

As an introduction, students could research and produce a historical timeline to illustrate the most significant scientific discoveries leading to the concept of the gene. The depth of treatment for the work of these scientists should be limited to their contribution to the understanding of DNA’s role as the hereditary molecule. The intent of this outcome is to show how scientific understanding progressed by building on the results of previous research. Geneticist to consider may include: (i) Mendel (ii) Sutton and Boveri(iii) Levene (iv) Griffith (v) MacLeod, McCarty,and Avery (vi) Chargaff (vii) Franklin and Wilkins (viii) Beadle and Tatum (ix) Hershey and Chase (x) Watson and Crick (xi) McClintock.

Students should describe, in general, how genetic information is contained in a DNA molecule (chromosome); how each DNA molecule replicates itself during cell division; and how information is transcribed into the base sequences of RNA molecules and is finally translated into the sequence of amino acids in cell proteins. Students could be asked to create/ perform simulations to demonstrate the replication of DNA, and the transcription and translation of its information. They could investigate the rarity of mistakes made during replication of DNA by discussing the role of DNA polymerase and its “proofreading” mechanism, and the influence of DNA repair enzymes.

Students should realize that DNA replication is a process in which a molecule of DNA is made containing one strand of parental DNA and one strand of new DNA. Students should understand that DNA replication is a four-step process (initiation, elongation, termination, proofreading and correction). Only make specific references to the enzymes DNA Helicase and DNA Polymerase during this process. During initiation the DNA molecule unwinds and unzips. Elongation involves the addition of complementary nucleotides to the original DNA strand. Termination is the completion of elongation, followed by proofreading and correction.

Regarding protein synthesis, it is not the intention to identify the specific enzymes involved in the process but rather the coordinated role of mRNA, rRNA, and tRNA in transcription and translation.

Students should be aware that environmental factors might cause a change in the expression of some genetic information of an organism (e.g. The two colour pattern of the Siamese cat involves one hair colour gene producing a temperature sensitive enzyme; the enzyme is active and produces dark pigment only on cooler areas of the body - feet,snout, tip of tail, ears). Sex may also play a role (e.g., baldness gene is only dominant in males). Other examples of the effects of the environment on gene expression include differences in identical twins and the colour of fur in Arctic foxes or hares. Time permitting, teachers could introduce the concept of epigenetics.

Content Knowledge

CK 2.3	*Learners are expected to ...*					
	analyse sources, types and effects of genetic variation.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
				■		

Achievement Indicators

Learners who have achieved this outcome should be able to …

a describe factors (spontaneous, mutagens) that may lead to mutations in a cell's genetic information;

b describe the types of mutations (point, chromosomal);

c analyse the effects of point mutations on protein synthesis; and

d analyse and interpret models of human karyotypes.

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

Elaborations

Students should be able to explain the meaning of mutation, what causes it, what is meant by a gene mutation and predict, in general, its effect on protein synthesis. They should be able to distinguish between somatic and germ mutation and compare the heritability of each. Regarding mutations that involve changes in nucleotide sequence, students should be able to distinguish between the two types of point mutations (i) Substitution (silent, mis-sense, nonsense); (ii) insertion/deletion (frameshift) as well as distinguish among the different types of chromosomal mutations (deletion, duplication, inversion, translocation). Furthermore, students should be introduced to mutations that involve changes in chromosome number (aneuploidy: nondisjunction resulting in trisomy, monosomy, etc.).

Other forms of genetic variation such as independent assortment and crossing over were introduced in specific curriculum outcome CK1.1. It should be emphasized that crossing over breaks gene linkages and can be another source of genetic variation in the nucleotide sequence.

CONTENT KNOWLEDGE

CK 3.1	*Learners are expected to ...*					
	describe historical and cultural contexts that have changed evolutionary concepts.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
		■				

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a recognize that by the Sixteenth Century the predominant paradigm in western culture was that all species of organisms came into existence at the same time and remained unchanged;

b describe the significance of the following individuals in the development of the theory of evolution by natural selection:

- Mary Anning;
- Georges Cuvier (include catastrophisim);
- Charles Lyell (include uniformitarianism);
- Jean Baptiste Lamarck (include acquired characteristics);
- Charles Darwin and Alfred Wallace; and
- Thomas Malthus (include competition).

c examine Darwin's observations and recognize how it led to his theory of natural selection; and

d compare Lamarck's and Darwin's explanations for changes in populations over time.

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

Elaborations

Evolution is a contentious concept for the members of some cultures and should be addressed with sensitivity. Evolutionary theory, however, is accepted by the scientific community; accounting for the diversity of life on Earth and explaining why life keeps changing.

To introduce this outcome, teachers may present videos, sourced online, depicting the development of Darwin's theory of evolution by natural selection and discuss how scientific research is analyzed within the scientific community. Teachers should encourage students to value the contributions to scientific and technological development made by individuals from many societies and cultural backgrounds.

The following activities/prompts may be useful in addressing components of CK3.1:

- Create an annotated timeline depicting the contributions of individuals leading to the development of the theory of evolution by natural selection.
- Darwin was unaware of the work of Mendel during his lifetime. How might knowledge of Mendel's inheritable factors have impacted Darwin's work? What does this say about how scientific knowledge develops?

Other considerations for assessment include:

- Create a podcast interviewing an individual of significance (who obviously no longer exist) in the development of the theory of evolution by natural selection.
- Design a social media page for an individual of significance in the development of the theory of evolution by natural selection.
- Discuss how acceptance of the theory of evolution by natural selection represents a paradigm shift.

Explain why natural selection is considered a scientific theory.

Content Knowledge

CK 3.2	*Learners are expected to ...*					
	analyze evolutionary mechanisms and their effects on biodiversity.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a define evolution as the relative change in genetic traits of populations that occurs over successive generations, include microevolution and macroevolution;

b describe how adaptations (i.e., structural, behavioural, physiological) develop as a result of gradual change in the genetic traits of members of a population over time, and improve the chances of survival and reproduction;

c describe how crossing over in meiosis, sexual reproduction, and mutation result in genetic variation within populations.

d explain the process of artificial selection, describing examples and discussing its impact on genetic diversity;

e explain the process of natural selection;

f evaluate and describe evidence to support the theory of evolution by natural selection; and

g explain how local environmental conditions exerting selective pressure on populations may result in extirpation or extinction.

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

Elaborations

Regarding achievement indicator CK3.2 f, students should evaluate and describe evidence supporting the theory of evolution by natural selection including:

- the fossil record, including index fossils, radiometric dating, and transitional fossils (Note: students are not expected to solve radiometric dating problems);
- biogeography examples;
- comparative anatomy, including homologous structures, analogous structures, convergent evolution, and vestigial structures;
- comparative embryology; and
- molecular biology and genetics, including DNA and protein comparisons.

The following activities/prompts may be useful in addressing components of CK3.2:

- Black Goldendoodle dogs are produced through artificial selection. Describe how this might be achieved.
- Explain how consistently using a fishing net with a mesh size of 15 cm^2 might change a cod population over the passage of time.
- As a result of climate change, polar bears are expanding their range into more southern environments. Predict how, over the passage of time, this might change the phenotypes of polar bears or lead to extirpation or extinction (related to CK 3.3).
- Analyze changes in beak depth of a Galapagos finch species and correlate changes in the finch population to changes in the environment.

Content Knowledge

CK 3.3	*Learners are expected to ...*					
	explain the evolution of new species.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
		■				

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a explain ways in which species become reproductively isolated, including geographic and biological barriers;

b describe how new species form (i.e., transformation, divergence [adaptive radiation]);

c describe how closely associated species may co-evolve; and

d describe gradualism and punctuated evolution models and recognize that both models are at work.

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

Elaborations

Specific curriculum outcome CK3.3 focuses specifically on how species evolve into new species. Teachers may introduce this content by presenting videos, sourced online, describing examples of speciation.

Examples of geographical barriers that teachers may want to address, include mountains, rivers, deserts, etc.. Examples of biological barriers that teachers may want to address include behavioural isolation, ecological/habitat isolation, temporal isolation, mechanical isolation, and gametic isolation, hybrid inviability, hybrid sterility, and hybrid breakdown.

Discussion on the evolution of new species can also be catalysed through the use of images and corresponding information about species that are closely related, or others that have co-evolved. The following activities/prompts may be useful in addressing/assessing components of specific curriculum outcome CK3.3:

- Severe flooding results in a river changing course. Would you expect a species of mouse that now lives on both sides of the river to eventually become two separate species? What about a species of bird that lives on both sides of the river?
- Refer to an image of Darwin's Finches. Interpret the speciation of the woodpecker finch and the large ground finch.
- Refer to an image of Darwin's Finches. How might adaptive radiation explain the speciation of the red crossbill?
- Refer to an image of Darwin's orchid and a hawk moth. Describe how these species might have co-evolved.
- Discuss how climate change might impact speciation and the pace of evolution, such as hybridization that may occur as a result of newly shared habitat (ex. Grizzly & Polar Bears)

Content Knowledge

CK 3.4	*Learners are expected to ...*					
	examine how the Hardy-Weinberg principle is used to determine whether a population is undergoing microevolution.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
				■		

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a define population genetics and gene pool;

b distinguish among genotype frequency, phenotype frequency, and allele frequency;

c describe the gene pool of a population at genetic equilibrium;

d summarize the five conditions upon which the Hardy-Weinberg principle is based;

e interpret data to determine whether a population is undergoing microevolution;

f analyze causes of gene pool change (linked to CK 3.2); and

g use Hardy-Weinberg equations to solve problems related to allele, genotype, and phenotype frequencies in a population, as well as the number of individuals with specific genotypes and phenotypes.

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

Elaborations

To introduce the Hardy-Weinberg principle, students could be asked to conduct an investigation to determine the effect of random mating on a large population, as well as the effect of a lethal recessive allele on allele frequencies in a large population using colored beads or beans. The focus should be on the analysis of individual and class data. (links to PK2) Students should be familiar with various forms of allele notation.

Furthermore, students could identify and compare the effects of genetic mutations, gene flow, non-random mating (i.e., sexual selection, inbreeding), genetic drift, and natural selection on gene pool diversity.

The following activities/prompts may be useful in addressing/assessing components of specific curriculum outcome CK3.4:

- Distinguish between:
  - founder and bottleneck effects;
  - stabilizing, directional, and disruptive selection
- Examine examples of how human activities affect the genetic diversity of natural populations. (e.g., commercial fishing, habitat loss, invasive species, over harvesting, dam/road construction, climate change, selective hunting, insecticide/herbicide use, antibiotic/antimicrobial cleaner use)
- Would a PEI Red Fox population achieve Hardy-Weinberg equilibrium? Explain.
- Is a population that is at genetic equilibrium evolving? Explain.
- Imagine that the first human mission to Mars was a success. A self-sustaining colony was established consisting of 3 females and 6 males, all of reproductive age. Identify reasons why this population would not achieve genetic equilibrium according to the Hardy-Weinberg principle.
- In a population that is in Hardy-Weinberg equilibrium, the frequency of the recessive allele A is 0.3. What percentage of individuals show the dominant trait?
- In a population of 800 mice that is in Hardy-Weinberg equilibrium, 128 mice express the recessive black fur trait. How many of the mice are heterozygous for fur colour?

Content Knowledge

CK 3.5	*Learners are expected to ...*					
	demonstrate an understanding of the fundamental principles of taxonomy.					
	Remembering	Understanding	**Applying**	Analysing	Evaluating	Creating

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a recognize that Earth's biodiversity can be explained both by genetic changes in populations over time and by major evolutionary changes that produce new species;

b explain how Earth's biodiversity can be classified into taxa (i.e. domain, kingdom, phylum, class, order, family, genus, species);

c explain the need for, and apply binomial nomenclature;

d demonstrate the use a taxonomic key to group and identify an organism;

e identify limitations of a given classification system and identify alternative ways of classifying to accommodate anomalies;

f describe the macroevolution of Bacteria, Archaea, Protists, Fungi,Plants, and Animals from an original cell, include endosymbiosis;

g recognize that phylogeny classifies organisms based on evolutionary relatedness, using homologous structures, fossil records, and genetic and molecular analyses as evidence; and

h interpret evolutionary trees by inferring relationships (most recent common ancestor, more closely related groups), identify clades, and identifing shared derived characteristics.

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

Elaborations

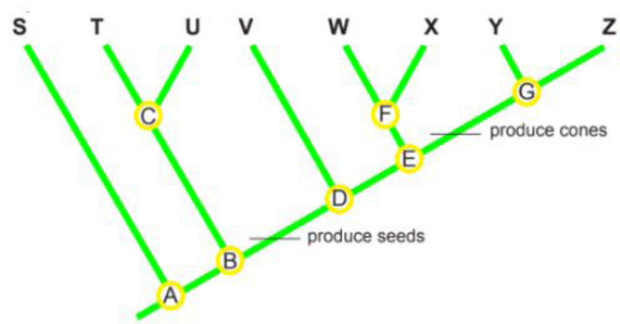
Students should recognize that biological classification systems change as new understandings of organisms emerge, often as a result of the invention of a technology. They should analyze and describe how advances in microscopy and genetic and molecular analyses revealed key differences among organisms and how the classification system was subsequently modified to better explain these differences.

Teachers may
- Present early biological classification systems and their limitations (Aristotle, Theophrastus to Linnaeus).
- Present collections of microscope slides representing bacteria, protists, fungi, and plants for students to examine.
- Model how to create a simple dichotomous key for a group of objects (e.g., backpacks, beads, buttons, nuts and bolts, shoes).
- Provide various field guides and dichotomous keys for students to use in identifying specimens.
- Have students create a dichotomous key for a group of objects.
- Discuss how some species challenge taxonomic categories. (Links to indicator CK 3.6 g, Protista)

Students could be provided with the information in the table below to answer the following:
- Which two organisms would you expect to share the greatest number of features?
- Which two species are least similar to the Siamese Cat?
- What evidence is there that otters share more features with mink than cats and dogs?
- Infer why biologists might group river otters, American mink, Siamese cats and Labrador retrievers in the same order.
- Predict some probable features of Alopex lagopus.
- Use the scientific name of one organism to explain binomial nomenclature.

Common Name	Order	Family	Scientific Name
Orca	Cetacea	Delphinidea	Orcinus orca
Little Brown Bat	Chiroptera	Vespertilionidae	Myotis lucifugus
River Otter	Carnivora	Mustelidae	Lontra canadensis
American Mink	Carnivora	Mustelidae	Neovison vison
Siamese Cat	Carnivora	Felidae	Felis domesticus
Labrador Retriever	Carnivora	Canidae	Canis lupus
Artic Fox	Carnivora	Canidae	Alopex lagopus

Students could be asked to answer the questions for the evolutionary tree below.
- What is the most recent common ancestor of groups Y and U?
- To which other groups is V most closely related?
- How many different clades are represented in this diagram?
- Explain why groups S, T, U, and their ancestors are not a clade.
- Which groups do not produce cones?



Content Knowledge

CK 3.6	*Learners are expected to ...*					
	describe the anatomy and physiology of organisms from each kingdom.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a identify distinguishing features among the three domains and six kingdoms (cell type, cell wall, nutrition, body form, nervous system, reproduction, locomotion);

b link the type of reproduction (asexual, sexual, both) to each kingdom;

c describe the differences that exist between Protista groups;

d describe the differences that exist between nonvascular and vascular plants;

e describe the differences between spore-bearing and seed-bearing vascular plants;

f describe the differences between gymnosperm and angiosperm seed bearing plants;

g explain why angiosperms are the most diverse plant group;

h identify and describe features used as evidence when classifying and hypothesizing evolutionary relationships among non-chordate animal groups;

i Identify a representative organism of each of the non-chordate animal groups;

j explain why arthropods are the most successful phylum of animals;

k describe features shared by all chordates; and

l identify a representative organism from each of the vertebrate classes.

Citizenship	✓ Critical Thinking	Personal-Career Development	**Essential Graduation Competencies**
✓ Communication	Technological Fluency	Creativity and Innovation	

Elaborations

Students should demonstrate an understanding that the six recognized kingdoms of living things represent a diversity of organisms exhibiting extensive variety in terms of form and function. Teachers should note that achievement indicator CK 3.6a is intended to provide students with a brief overview of biodiversity. As such, distinguishing features among the three domains and six kingdoms should be limited to cell type, cell wall, nutrition, body form, nervous system, reproduction, and locomotion. For consistency, clarity and ease of comparison of distinguising features, students could be provided with a table to record the physical traits used to distinguish representative organisms of the 6 kingdoms. The student tables presented could be treated as prompts for resource-based learning activities whereby students access resources outside the textbook to develop their knowledge. Teachers may provide a collection of physical specimens or images from different taxonomic groups and ask students to examine and group them based on their features, explaining their thinking aloud.

When available, representative organisms from a local ecosystem can be identified. Students may use field guides and mobile device applications (e.g. Leafsnap, PlantSnap, PictureThis, Picture Insect, iNaturalist) to identify local specimens (e.g., plants, birds, or insects).

Protista

Students should describe the general characteristics (cell wall, motility, nutrition, mode of reproduction) that differentiate the Protista groups (Protozoa, Algae, Slime and Water Moulds). Although students should have a general appreciation for these characteristics that contribute to the diversity of the three major groups, they should also appreciate the plant-like, animal-like, and fungus-like attributes of these major groups as well.

Plants

As it is impossible to include a complete summary of the plant phyla, our focus will be on the comparison of non-vascular and vascular plants. Within vascular plants the focus will be on the advantageous of seeds over spores, and the describing the various methods of pollination and seed dispersal in the angiosperm group.

Non-Chordates

Students should identify and describe features used as evidence when classifying and hypothesizing evolutionary relationships among non-chordate animal groups (i.e., Porifera, Cnidaria, Platyhelminthes, Annelida, Mollusca, Arthropoda, Nematoda, Echinodermata), including, but not limited to:

- presence of specialized tissues (i.e., nerves);
- body plan symmetry (i.e., asymmetry, radial, bilateral);
- embryonic cell layers (i.e., monoblastic, diploblastic, triploblastic);
- coelom presence/absence;
- digestive systems (complete/incomplete);
- Cephalization;
- Motility; and
- Segmentation.

Chordates

Students should identify the features shared by all chordates (e.g. notochord, dorsal hollow nerve cord, pharyngeal slits, post anal tail). Furthermore, they should identify and the describe features (endoskeleton, respiration, circulation, reproduction, and temperature regulation) from each of the vertebrate classes (chondrichthyes, osteichthyes, amphibia, reptilia, aves, mammalia).

Students are expected to investigate the anatomy and physiology of animals, through
- examination of live or preserved specimens of representative animals;
- examination of prepared slides of representative animals and their structures (e.g., sponge, hydra, daphnia, planaria, earthworm, ascaris, hookworm, tapeworm, drosophila, leeches); and
- dissection of preserved or fresh specimens of representative animals (e.g., earthworm, grasshoppers, scallop, mussel, squid, crayfish, crab, sea star, sea urchin, sea cucumber).

Content Knowledge

CK 4	*Learners are expected to ...*					
	analyse the impact of infectious, genetic, and environmental diseases on the homeostasis of the system and the organism as a whole.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
				■		

Achievement Indicators

Learners who have achieved this outcome should be able to ...

a describe the signs and symptoms of the disease;

b identify the cause of the disease (infectious, genetic, environmental);

c analyse how a disease impacts the normal functioning of the affected system(s);

d analyse how a disease impacts the normal functioning of the organism;

e describe available cures and/or treatment of symptoms.

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

Elaborations

This outcome can be addressed independently or in conjunction with complementary outcome NoS1 where students must evaluate the development of a technology related to the diagnosis and treatment of a disease. Furthermore, this outcome can be addressed by having students engage in a research project giving them agency (voice and choice) over the topic and mode of presentation. The project can take on many forms, one of which is a “speakers series” or “video series” where brief student presentations or videos are scheduled to occur throughout the duration of the course at times that may coincide with the topic being studied.

A variety of diseases that students could analyse may include:

- Reproductive System: HIV and AIDS, chlamydia, hepatitis B, genital herpes, syphilis, gonorrhea;
- Embryonic Development: teratogens (cigarette smoke, alcohol, prescription drugs) on embryo development;
- Genetics: autosomal recessive inheritance (e.g., Tay-Sachs, PKU); co-dominant inheritance (e.g., sickle cell anemia); autosomal dominant inheritance (e.g., progeria, Huntington’s); incomplete dominant inheritance (e.g., FH); and x-linked recessive inheritance; (e.g., color blindness, muscular dystrophy, hemophilia); chromosomal mutations (e.g., Down syndrome, Turner syndrome, Klinefelter syndrome (XXYsyndrome), Jacobs syndrome (XYY syndrome), and Triple X syndrome3); and higher risk if a family member had the disease (e.g. Alzheimer’s); and
- Plant Reproduction/Growth related to our PEI agriculture industry (e.g., blight, verticillium wilt, potato wort).

While the terms disease, disorder, and syndrome are often used interchangeably, they actually have a specific meaning that are unique. Although this outcome and it’s achievement indicators reference the term disease, students can analyse disorders and syndromes.

Appendix A: The Scientific 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

Appendix A: The Scientific Continuum

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 B: 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.

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).

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.)

References

Council of Atlantic Ministers of Education and Training. (2007). *Cross-curricular Reading Tools*. Halifax, NS: Author.

Council of Atlantic Ministers of Education and Training. (1998). *Foundation for the Atlantic Canada Science Curriculum*. Charlottetown, PE: Author.

Councils of Ministers of Education, Canada. (1997). *Common Framework of Science Outcomes K–12*. Toronto, ON: Author. Retrieved from https://archive.org/details/commonframework00coun.

Dombrowski, E., Rotenberg, L., Bick, M. (2013). *Theory of Knowledge Course Companion*. Oxford: Oxford University Press.

Elliott, P. (2010). Science and Literacy in the Elementary Classroom [Monograph]. *What Works? Research into Practice, 26.* Retrieved from http://www.edu.gov.on.ca/eng/literacynumeracy/inspire/research/WW_science_literacy.pdf.

Flick, L.B., Lederman, N.G. (Eds.). (2006). *Scientific Inquiry and Nature of Science: Implications for Teaching, Learning, and Teacher Education*. Netherlands: Springer Academic Publishers.

Gauch, H.G. Jr. (2009). Science, Worldviews, and Education. *Science & Education*. *18(6-7)*, 667-695.

Glickman, C. (1991). Pretending Not to Know What We Know. *Educational Leadership. 48(8)*, 4-10.

Harvey, S., Goudvis, A. (2007). *Strategies that Work: Teaching Comprehension for Understanding and Engagement.* Portland, ME: Stenhouse Publishers.

Howes, E.V., Lim, M., Campos, J. (2008). Journey into Inquiry-based Elementary Science: Literacy Practices, Questioning, and Empirical Study. *Science Education.93,* 189-217.

Klein, P. (2008). Content Literacy [Monograph]. *What Works? Research into Practice, 13.*

Kozak, S., Elliot, S. (2014). *Connecting the Dots, Key Stages that Transform Learning for Environmental Education, Citizenship and Sustainability.* Oshawa, ON: Maracle Press Ltd.

Krathwal D.R. (2002). A Revision of Bloom's Taxonomy, An Overview. *Theory into Practice*. *41(4),* 212-218.

Llewellyn, D. (2013). *Teaching High School Science Through Inquiry and Argumentation.* California: Corwin.

Marzano, R.J. (2009). Setting the Record Straight on "High-Yield Strategies". *Phi Delta Kappan. 91(1),* 30-7.

Marzano, R.J., Pickering D.J., Pollock J.E. (2004). *Classroom Instruction that Works: Research-based Strategies for Increasing Student Achievement.* Alexandria, VA: Association for Supervision and Curriculum Development.

Marzano, R.J., Toth M.D. (2014). Teaching for Rigor: A Call for a Critical Instructional Shift [Monograph]. *Learning Sciences International*. Retrieved from http://www.marzanocenter.com/files/Teaching-for-Rigor-20140318.pdf

Michaels, S., Shouse, A.W., Schweingruber, H.A. (2008). *Ready, Set, Science! Putting Research to Work in K–8 Science Classrooms.* Washington, D.C.: The National Academies Press.

National Research Council. (2012). *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.: The National Academies Press.

Next Generation Science Standards Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, D.C.: The National Academies Press.

References

Organisation for Economic Co-operation and Development. (2013). *PISA 2015 Science Framework Draft*. Author. Retreived from https://www.oecd.org/pisa/pisaproducts/pisa2015draftframeworks.htm.

Oleckno, W.A. (2002). *Essential Epidemiology: Principles and Applications*. Illinois: Waveland Press, Inc.

Ontario Ministry of Education. (2008). *Grades 9 and 10 Science Curriculum Document (revised).* Ontario: The Queen's Printer of Ontario.

Perry, M.C. (2013). Changes in Food and Habitats of Waterbirds. *Synthesis of U.S. Geological Survey Science for the Chesapeake Bay Ecosystem and Implications for Environmental Management. 14.* U.S. Department of the Interior. Retrieved from https://pubs.usgs.gov/circ/circ1316/html/toc.html.

Santrampurwala, S., Lekanides, K., Rothwell, A., Rutherford, J., Trudgon R. (2013). *Theory of Knowledge for the IB Diploma*. Oxford: Oxford University Press.

Saskatchewan Ministry of Education. (1991). *Instructional Approaches - A Framework for Professional Practice*. Saskatchwan. Author.

Schick, T., Vaughn, L. (2014). *How to Think About Weird Things: Critical Thinking for a New Age.* New York: The McGraw-Hill Companies.

Schmidt, B. (n.d.). STEM 101: A Primer, what is STEM? Retrieved from https://canada2067.ca/en/articles/stem-101-what-is-stem/

Schmoker, M.J. (2011). *Focus: Elevating the Essentials to Radically Improve Student Learning*. Alexandria, Va: Association for Supervision and Curriculum Development.

Sharratt, L., Fullan, M. (2012). *Putting Faces on the Data.* California:Corwin.

Shermer, M. (2011). What is Pseudoscience?. *Scientific American.* Retrieved from: https://www.scientificamerican.com/article/what-is-pseudoscience/.

Sterman, J.D. (2000). *Business Dynamics*. Boston: McGraw-Hill, Inc.

Tompkins, G.E., Campbell, R., Green, D., Smith, C. (2015). *Literacy for the 21st Century: a Balanced Approach (2nd edition).* Melbourne: VIC Pearson Australia.

University of California Museum of Paleontology. (2016). Understanding Science how science really works. Retrieved from: http://undsci.berkeley.edu.

Wieman, C. (2002). PhET Interactive Simulations: University of Colorado Boulder. Retrieved from: https://phet.colorado.edu/.

Wiggins, G., McTigh, J. (2005). *Understanding by Design Expanded Second Edition*. Alexandria, VA: Association for Supervision and Curriculum Development

Youth Science Canada. (2011) *Smarter Science, Introducing the Framework*. Author. Retrieved from: https://smarterscience. youthscience.ca/about-0.