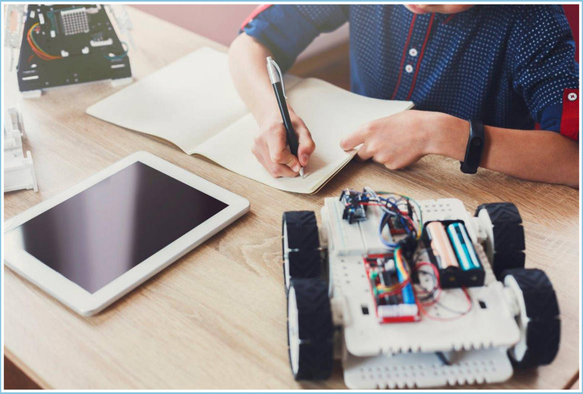
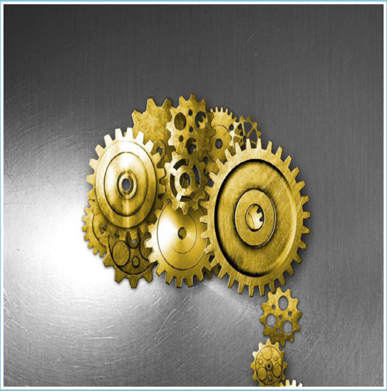
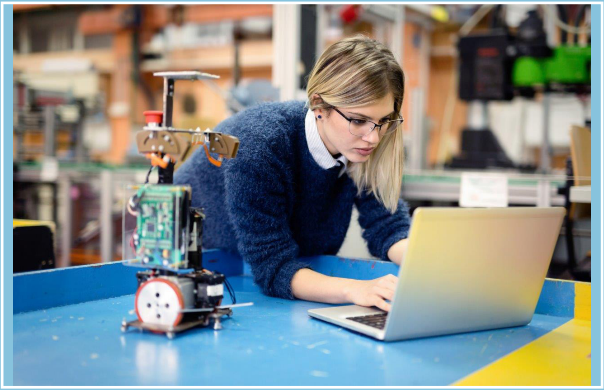
SCI701A



SCIENCE

Applied Science





Curriculum Guide

Prince Edward Island
CANADA

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Overview of Applied Science SCI701A

Course Description

SCI701A is a physical science course that develops students' scientific and technological knowledge and skills through the use of technology and a robotics design and construction context. It contains a balance of theory, design, and experimental activities that builds student scientific and technological literacy using the processes of inquiry, problem solving, and decision-making. In a collaborative environment, this course will provide opportunities for those students interested in careers related to applied technology, engineering, and the skilled trades.

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 (CAMET) in The Atlantic Canada Framework for Essential Graduation Competencies (2015). To facilitate this shift to competency-based education, a number of significant changes have been incorporated in this guide: 1) specific curriculum outcomes (SCOs) have been reduced and targeted toward EGCs; 2) greater emphasis has been placed on processes and skills; and 3) achievement indicators (AIs) have been included to clarify the "depth and breadth" of SCOs.

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.

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.

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.

Knowledge Dimension

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

Table 2. Bloom's Taxonomy—Knowledge Dimension

Category	Description
Factual	The basic elements students must know to be acquainted with a discipline or solve problems in it (e.g., knowledge of terminology; knowledge of specific details and elements).
Conceptual	The interrelationship among the basic elements within a larger structure that enables them to function together (e.g., knowledge of classifications and categories, knowledge of theories, models, and structures).
Procedural	How to do something, methods of inquiry, and criteria for using skills, algorithms, techniques, and methods (e.g., knowledge of subject-specific skills and algorithms, knowledge of subject-specific techniques and methods, knowledge of criteria for determining when to use appropriate procedures).
Metacognitive	Knowledge of cognition in general as well as awareness and knowledge of one's own cognition (e.g., strategic knowledge, knowledge about cognitive tasks, including appropriate contextual and conditional knowledge, self-knowledge).

Taxonomy Tables

Combining the cognitive process dimension and knowledge dimension into one taxonomy table helps teachers to visualize the overall expectations. As teachers reflect deeply and collaborate to identify the types of cognition and knowledge required by each outcome, they will be better able to plan what student achievement will look, sound, and feel like in the learning environment, leading to student achievement of the outcomes at the targeted level.

The taxonomy tables in the PEI curriculum guides are constructed as two-dimensional tables where the knowledge dimension forms the vertical axis and the cognitive process dimension forms the horizontal axis. This results is a 24-cell matrix on which any specific curriculum outcome can be classified in terms of both dimensions.

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: describe
cognitive process: UNDERSTANDING

PK 5 - describe how STEAM informs product development.

noun: STEAM
knowledge: CONCEPTUAL

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 3. Details of Curriculum Guide Layout

Feature	Description
Unit Name	Appears in the upper left hand corner.
Taxonomy Table	Appears in the upper right hand corner and is specific to the given outcome.
SCO Block	Appears in the coloured box; may contain a scope and sequence chart.
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

Taxonomy Table for this particular SCO

NoS 1		Cognitive Process Dimension					
		Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Knowledge Dimension	Factual						
	Conceptual						
	Procedural						
	Metacognitive						

Specific curriculum outcome (SCO)

NoS 1	*Learners are expected to ...*
	describe how STEAM informs product development.

Achievement Indicators

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

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

a describe the basic components of STEAM;

b describe how STEAM processes can be used to answer societal questions;

c research a product or a device and describe how each component of STEAM contributes to its' development;

d describe STEAM related careers involved in the development of a product or device; and

e describe relationships between STEAM and the Nature of Science (e.g., peer review, evidence based, satisfies curiosity, collaboration, critical thinking, creative, transdisciplinary, iterative process, etc)

Essential Graduation Competencies Map

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

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Figure 3. *Sample of a curriculum guide page*

Footer indicates the Course Name and the Course Code.

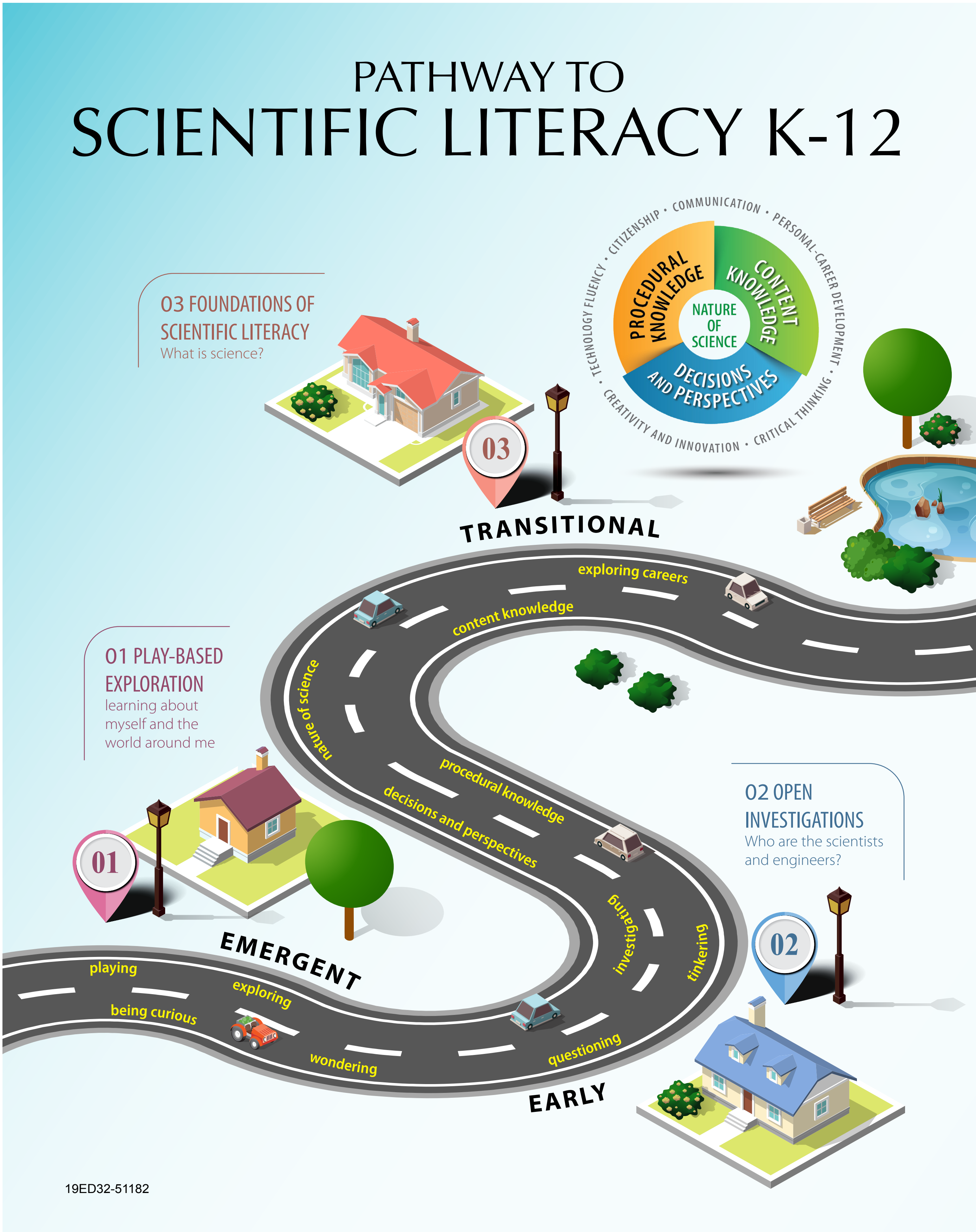
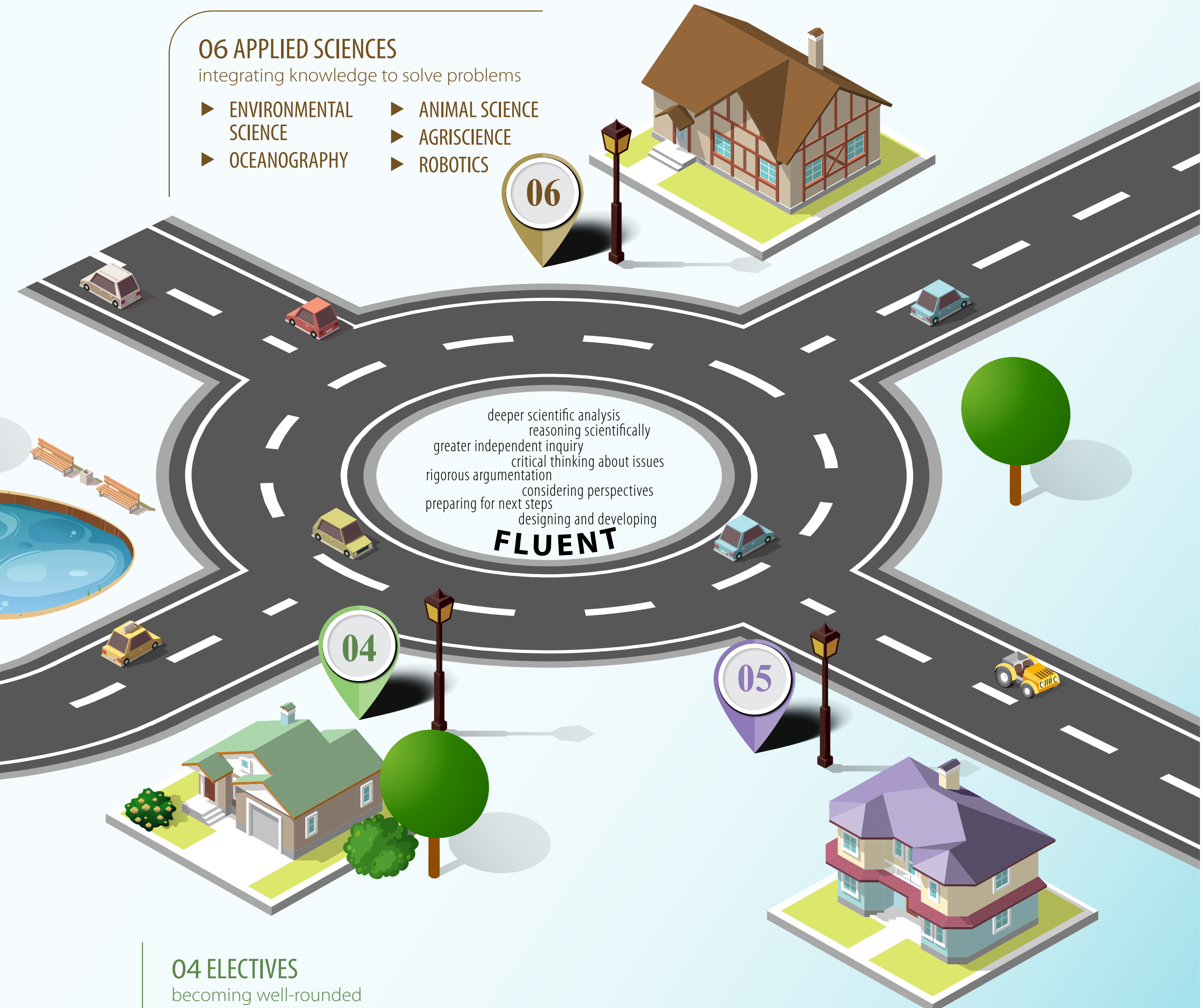


Figure 4. *Pathways to Scientific Literacy*

06 APPLIED SCIENCES

integrating knowledge to solve problems

- ENVIRONMENTAL SCIENCE
- OCEANOGRAPHY
- ANIMAL SCIENCE
- AGRISCIENCE
- ROBOTICS



04 ELECTIVES

becoming well-rounded

- MATH
- BUSINESS
- ENTREPRENEURSHIP
- CAREER TECHNICAL EDUCATION
- ART
- CO-OP EDUCATION
- INDEPENDENT STUDY
- FLEXIBLE LEARNING OPPORTUNITIES
- COMPUTER SCIENCE

05 CORE DISCIPLINES

digging deeper into content knowledge

- BIOLOGY
- CHEMISTRY
- PHYSICS

Overview

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

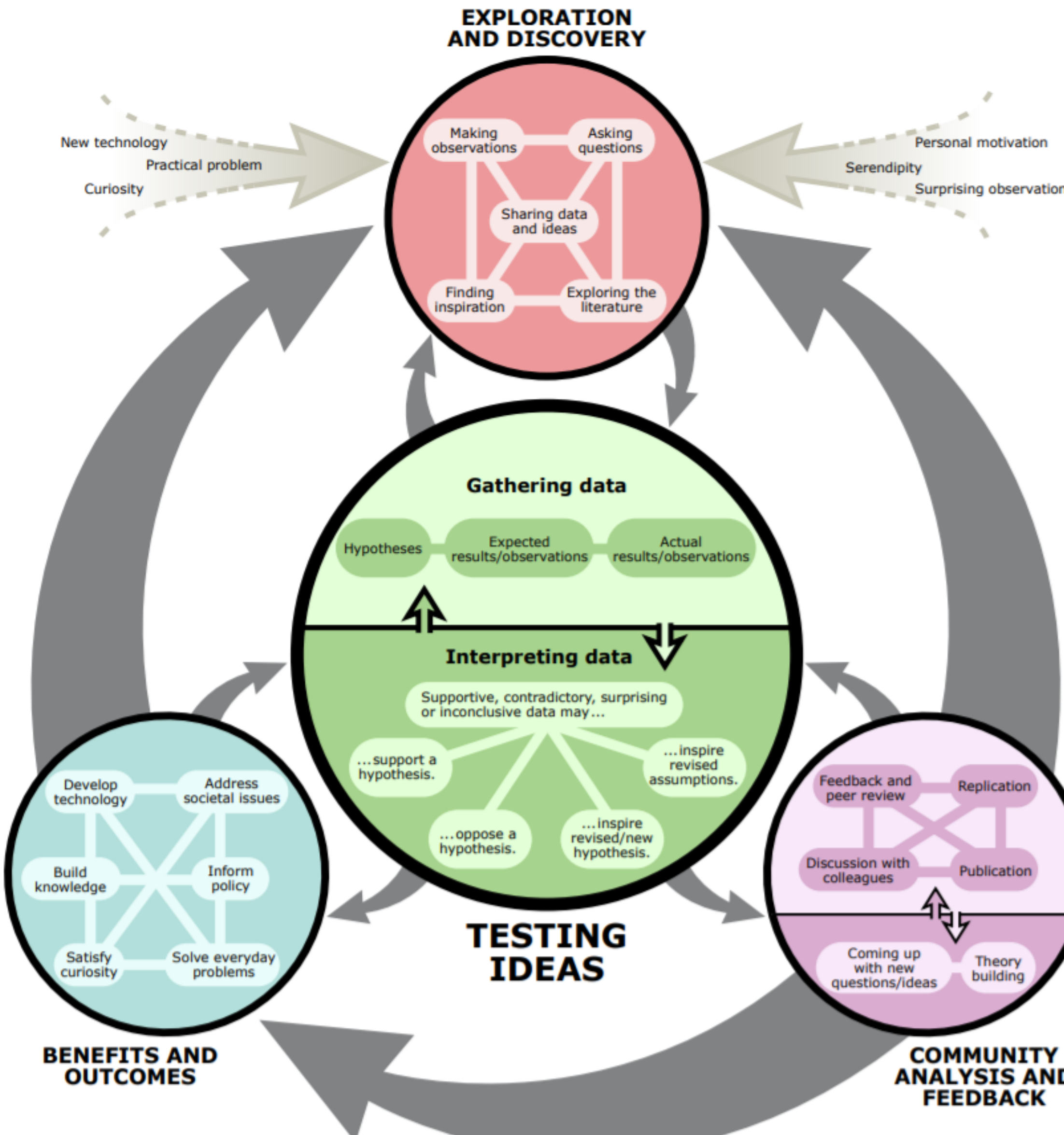


Figure 5. *How Science Works (University of California Museum of Paleontology 2016)*

Nature of Science

What is science?

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

> *"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)*

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 7), 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

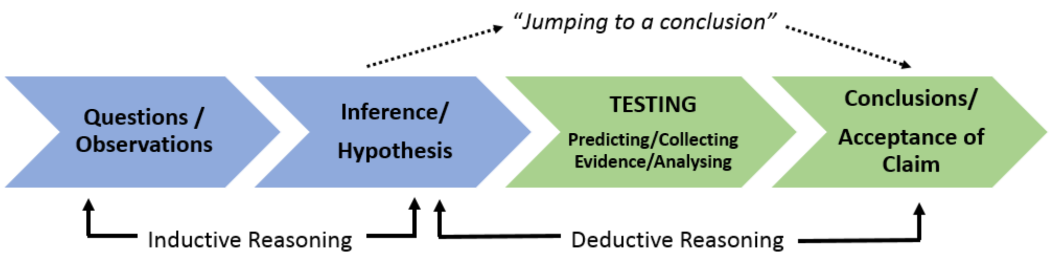


Figure 6. *Scientific reasoning*

Science Language is Precise

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

- A fact is a readily verifiable observation that is generally accepted (e.g., if you drop a coin from your hand, it will fall to the Earth). Facts in science are still open to inquiry and therefore able to change.
- Hypotheses are tentative explanations describing a causal relationship. Hypotheses are not guesses but stem from problems, questions, observations, logic, other hypotheses, and theories. The development of a hypothesis involves elements of curiosity, creativity, imagination, and intuition. Hypotheses lead to predictions of what will happen under a given set of circumstances (i.e., tests or investigations). Hypotheses can be accepted, rejected, or modified as a result of evidence. While hypotheses can never be proven true with 100% certainty, they can be proven to be false. Many varied hypotheses can be generated from one new scientific idea.

> *"Hypotheses are created, not discovered, and the process of their creation is just as open-minded as the process of artistic creation."*
> *(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

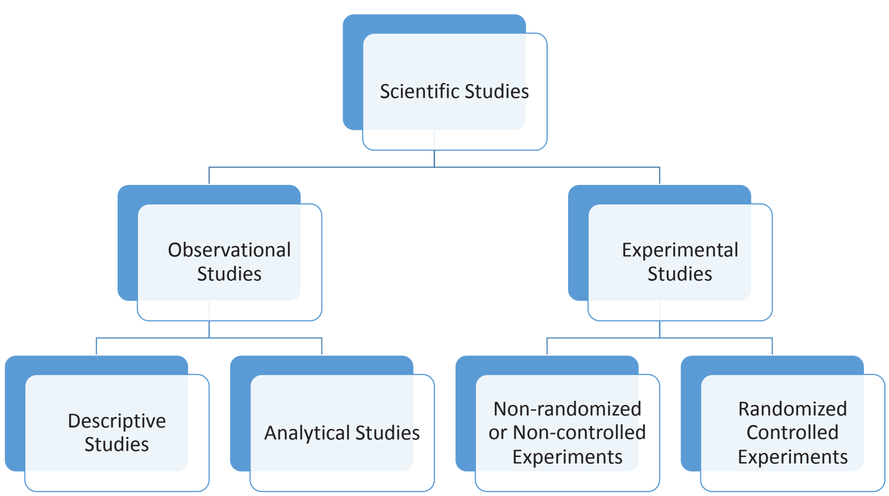


Figure 7. *Classification of scientific studies. Adapted from Oleckno, 2002*

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 7) vary depending on the question being asked, the process of developing new scientific knowledge always involves a number of aspects or stages (Figure 8). These aspects include asking testable questions about the natural world, collecting and analyzing evidence to answer those questions in a logical manner, and sharing that knowledge with other experts so that it can be skeptically reviewed and validated by other lines of evidence. Each stage of scientific inquiry is associated with specific skills and competencies (Table 4).

Stages of Scientific Inquiry

Initiating and Planning

Performing and Recording

Analysing and Interpreting Data

Communicating Findings

Figure 8. *Scientific inquiry process wheel*

Foundations of Scientific Literacy: Procedural Knowledge

Table 4. 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 9)*
- *flow charts that depict energy flow in a food web (Figure 10) or electricity transmission rates (Figure 11)*

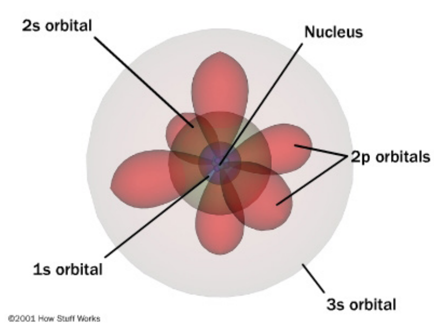


Figure 9. *The quantum mechanical model of the atom*

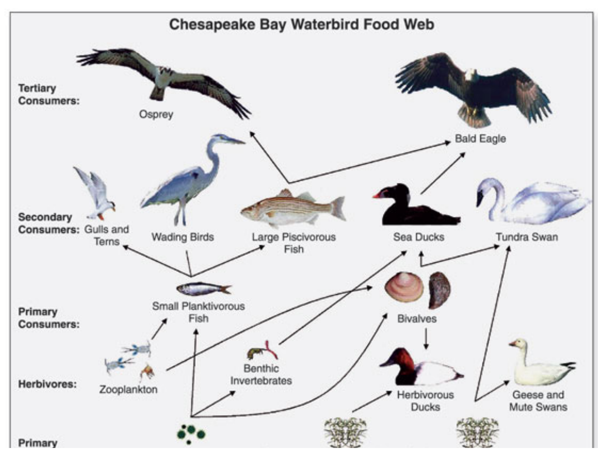


Figure 10. *Energy flow in a food web. (Perry 2019)*

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.

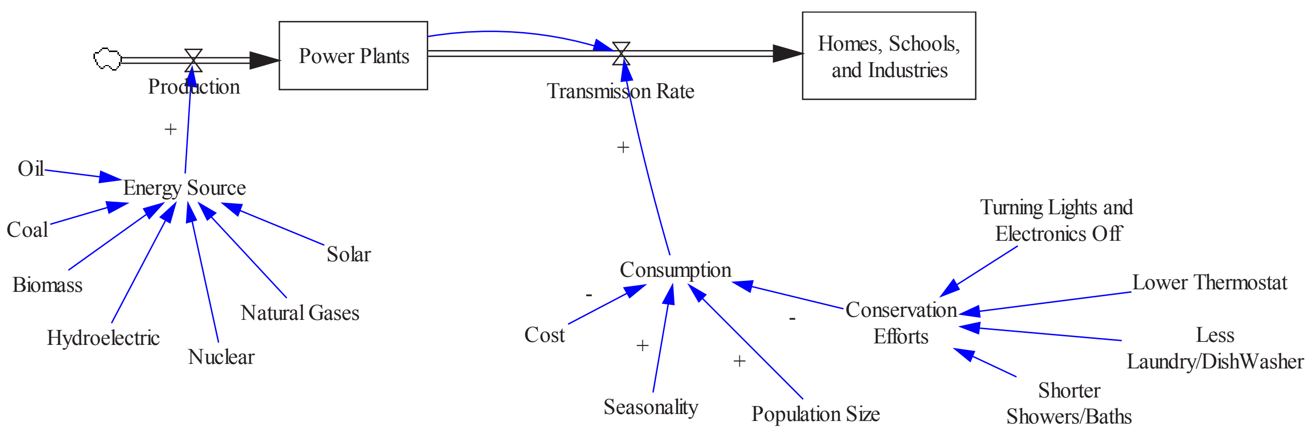


Figure 11. *A stock and flow conceptual model*

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 5. 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 12. *Generic problem-solving process*

Figure 13. *A comparison of STEAM problem-solving processes*

Interdisciplinary Skills

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

Mathematical Skills

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

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

Technology Skills

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

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.

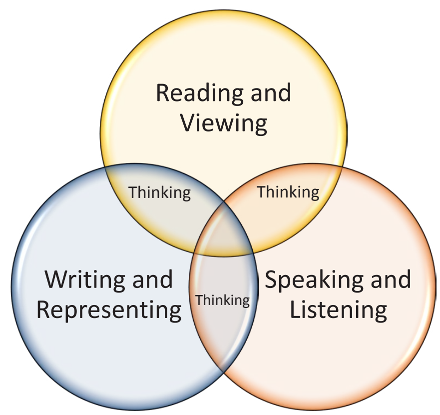


Figure 14. *The nature of language arts*

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.

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

Instructional Strategies

> *"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.

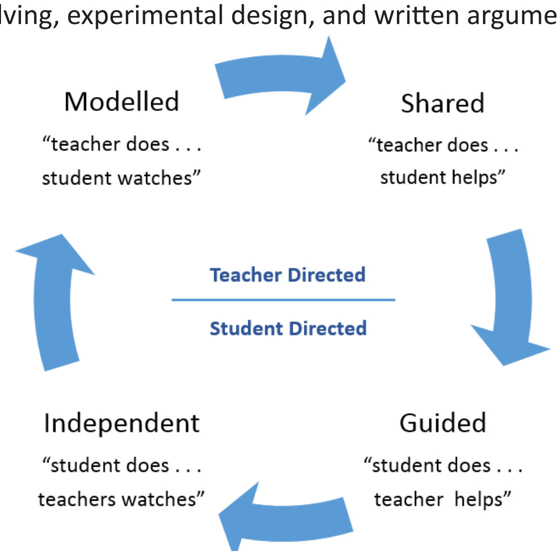


Figure 15. *Gradual release of responsibility*

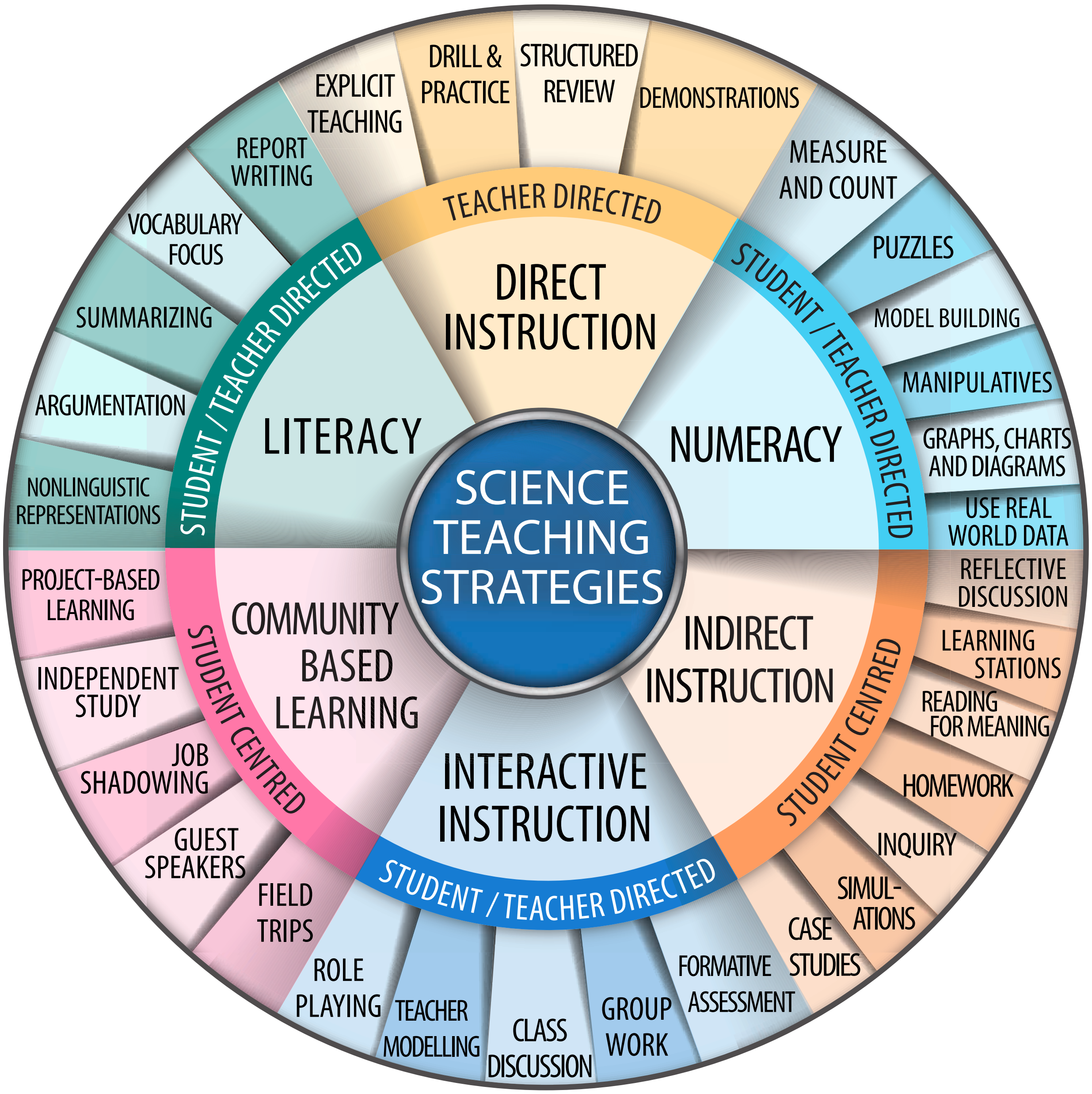


Figure 16. *Science teaching strategies*

Assessment and Evaluation

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 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.

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 6. 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

Outcome Summary

The outcomes of SCI701A are categorized into four scientific literacy foundations (Nature of Science, Decisions and Perspectives, Procedural Knowledge and Content Knowledge). Table 7 below shows the summary of specific curriculum outcomes for SCI701A. Each specific curriculum outcome with the related achievement indicators and elaborations can be found starting on page 40.

Table 7. Summary of Curriculum Outcomes

GCO	Code	Specific Curriculum Outcome
Nature of Science; Decisions and Perspectives	NoS 1	describe how STEAM informs product development.
	DP 1	argue for or against the application of a scientific or technological development while demonstrating respect for the perspectives of others.
Procedural Knowledge	PK 1	collaborate with team members to assemble and design a device.
	PK 2	communicate ideas, plans, results, and concepts using appropriate numeric, symbolic, graphical, and linguistic modes of representation.
	PK 3	measure quantities and perform measurement conversions.
	PK 4	assemble and analyse the design of a device, and troubleshoot problems as they arise.
	PK 5	create a device to perform a simple task using an engineering design process.
Content Knowledge	CK 1	describe the main components and basic function of robot subsystems.
	CK 2	perform calculations involving translational speed, rotational speed, and torque.
	CK 3	analyse power transmission problems involving gear ratios.
	CK 4	describe how traction and turning are affected by friction.
	CK 5	describe the design and interrelationship among object manipulators, rotating joints, and linkages used in mechanical systems.

Taxonomy Table

Table 8 on the following page shows where SCI701A outcomes sit within Bloom's Taxonomy. Refer to page 10 and page 11 for descriptions of the Cognitive Process and Knowledge Dimensions. An SCO that appears more than once in this taxonomy table has multiple assessable targets.

Table 8. Bloom's Taxonomy Table for SCI701A

		Cognitive Process Dimension					
		Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Knowledge Dimension	Factual						
	Conceptual		NoS 1, CK 1, CK 4, CK 5	CK 2	CK 3, PK 4	DP 1	
	Procedural			PK 2, PK 3, PK 4		PK 1	PK 5
	Metacognitive						

Table of Specifications (TOS)

A table of specifications (TOS) is a two-way table that describes the relative weighting of each unit or cluster of outcomes within a scientific literacy foundation. The TOS also provides the relative weighting of summative assessment levels within a course ("Appendix C: Characteristics of TOS Assessment Levels" p.67 for a description of Levels 1–3). While the primary purpose of a TOS is to designate the cognitive demands for summative assessments, it can also be used to provide insight when planning instruction and other forms of assessment. An SCO that appears more than once in this taxonomy table has multiple assessable targets.

Table 9. Table of Specification for SCI701A

Foundation/GCO	Level 1	Level 2	Level 3	Weight of GCO
Nature of Science; Decisions and Perspectives	NoS 1			**15%**
			DP 1	
Procedural Knowledge			PK 1	**55%**
		PK 2		
		PK 3		
		PK 4 PK 4		
			PK 5	
Content Knowledge	CK 1			**30%**
		CK 2		
		CK 3		
	CK 4			
	CK 5			
Weight by Level	**30%**	**45%**	**25%**	

Nature of Science

NoS 1		Cognitive Process Dimension					
		Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Knowledge Dimension	Factual						
	Conceptual						
	Procedural						
	Metacognitive						

NoS 1	*Learners are expected to ...*
	describe how STEAM informs product development.

Achievement Indicators

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

a describe the basic components of STEAM;

b describe STEAM as a transdisciplinary approach to solving societal problems;

c research a product or a device and describe how each component of STEAM contributes to its' development;

d describe STEAM related careers involved in the development of a product or device; and

e describe relationships between STEAM and the Nature of Science (e.g., peer review, evidence based, satisfies curiosity, collaboration, critical thinking, creative, transdisciplinary, iterative process, etc)

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

Elaborations

Specific Curriculum Outcome NoS1 can be addressed, in part, by providing students with an opportunity to complete a project involving the identification of a product whose materials, design, and function are informed by STEAM. This project can also be used to address specific curriculum outcome DP1.

STEAM stands for Science, Technology, Engineering, Arts, and Mathematics. But there is more to the 'STEAM' label than these subject areas. "It has become a short-form label that includes a diverse set of 21st century skills and characteristics—ways of thinking about (and solving) the problems that we all face as global citizens" (Schmidt, n.d.). Students should be provided with a basic understanding of the components of STEAM followed by videos illustrating STEAM in action in solving problems or in designing and constructing devices. The videos should provide insight into the depth and breadth of STEAM as an transdisciplinary approach to thinking about the natural world and informing the processes involved in solving complex societal issues.

Student should be provided with examples of how practical skills (skills that we typically associate with STEAM) contribute to the design and production of everyday products (sporting equipment, food, toys, industrial components, everyday tools, etc). They should also be provided with examples of how fundamental skills (logical reasoning, critical thinking, and problem-solving) that we use every day when we evaluate a problem, identify resources, construct a solution, and execute plans, contribute to STEAM projects.

Having researched product development and the integral role STEAM plays in the development of a product students might wonder how they may become involved in a STEAM related career. Students could be provided with a list of STEAM related jobs and asked to identify one related to their project that they may be interested in pursuing. They could create a career profile using a variety of formats, such as a Web page, podcast, or poster. In the profile, the students should

- describe the career (duties, responsibilities, time commitment);
- identify the educational requirements;
- identify key skills that are required to be successful at this career;

Students or the instructor may consider inviting a professional from the community in to class as a guest speaker. Furthermore, a class career day could be created by congregating all guest speakers on a particular day.

Decisions and Perspectives

DP 1		Cognitive Process Dimension					
		Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Knowledge Dimension	Factual						
	Conceptual						
	Procedural						
	Metacognitive						

DP 1	*Learners are expected to ...*
	argue for or against the application of a scientific or technological development while demonstrating respect for the perspectives of others.

Achievement Indicators

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

a select and integrate information from various print and electronic sources or from several parts of the same source;

b identify a technological or scientific development that addresses a human need or practical problem (e.g., energy source, electric cars, nanotechnology, drones, mass production technologies, artificial intelligence, medical technologies, robotics);

c analyse the advantages and disadvantages of a scientific or technological development using an evaluative technique such as plus-minus comparison, risk-benefits analysis, SWOT analysis (strength, weakness, opportunities, threats), etc.;

d construct arguments to support a decision or judgment, using examples and evidence and recognizing various perspectives;

e propose courses of action on social issues related to science and technology, taking into account an array of perspectives; and

f identify their personal beliefs and biases related to a scientific or technological development and recognize how perspectives are influenced by a variety of factors (e.g., age, gender, culture, socioeconomics, values, geographic region).

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

Elaborations

This specific curriculum outcome can be addressed by providing students with an opportunity to engage, individually or collaboratively, in a research project that would require them to use print and electronic resources to research, select, and integrate information on a scientific or technological development. Elements of specific curriculum outcome NoS1 may also be considered when planning this research project.

For instance, students could be asked to select a science or technology development of interest; discuss the viability of its long-term use; consider from an array of perspectives (e.g., health, economics, policy, and the environment) the risks and benefits; and give a brief history of the subject. Sustainability and other issues may be considered.

Topics could include: GPS vehicle control: alternative energy; automated checkout; robotic surgery; electric cars; nanotechnology, drones, artificial intelligence; mass production technologies; etc.). Students should be asked to present their project to the class. Class presentations will provide opportunities for students to use evidence to construct arguments in support of decisions they have made about the science or technology development. Through questioning, students will be exposed to different perspectives and, as a result, will be expected to better appreciate the importance of peer review in the development of scientific knowledge.

Every technology comes with risk benefits and risks. It is important for students to be able to view risk and benefits of a technology from multiple perspectives. Having researched a technology, students will be expected to make a claim regarding wether the benefits outweigh the risks. What is important is that their claim is supported with evidence, and explanations that clearly link their evidence to the claim they are making. The use of writing frames, like the one provided below, can be used to help students plan their argument.

Claim, Reasoning, Evidence

Your answer to the question given is your claim. The data or evidence that helped you arrive at this claim is your evidence. Write down your claim and your evidence in the corresponding boxes below.

CLAIM	 REASONING	EVIDENCE

You will note that sandwiched between claim and evidence is reasoning. Reasoning is the "bridge" between your answer to the question (i.e., the claim) and the data that led you to that answer (i.e., evidence). In your own words, write down in the reasoning box above **why** or **how** your evidence supports or justifies your claim. Together, your claim, evidence and reasoning form your evidence-based argument.

Figure 17. *Claim, Reasoning, Evidence*

Content Knowledge

CK 1		Cognitive Process Dimension					
		Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Knowledge Dimension	Factual						
	Conceptual		■				
	Procedural						
	Metacognitive						

CK 1	*Learners are expected to ...*
	describe the main components and basic function of robot subsystems.

Achievement Indicators

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

a describe the conditions necessary for a device to be considered a robot;

b describe the function of the six subsystems (structure, motion, control, sensor, power, and logic) of a robot; and

c identify key components of each of the six robotic subsystems, and describe their function.

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

Elaborations

There are varied opinions on the definition of a robot which often stem from the degree of automaticity/human input. For the purposes of Applied Science 701A we will draw upon the International Organization for Standardization (ISO) who defines a robot as an "actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks" (ISO, 2012).

As an introduction to this specific curriculum outcome, student groups can be given a variety of pictures of mechanical devices, some considered robots and others not. The group task would be to review the pictures and identify which image(s) they believe to be robots. Each group can then create an operational definition of a robot which can be shared with the class and later compared to the definition provide by ISO.

Students are expected to identify the basic components of a robot and their functions. These include the body, control system, CPU, and output devices (behaviour). Each part involved in the construction of a robot falls into one of six subsystems. The subsystems include structure, motion, power, sensor, logic, and control. Students are expected to identify and describe the six categories of robot subsystems and the key components associated with each. To assist in addressing this outcome and in managing resources, student teams could create a parts inventory. This activity may also help clarify the functions of the individual components of the robot subsystems.

Student can be tasked to create a graphic organizer to assist with the learning, or assessment, of this outcome. A mind map could be created with "ROBOTICS" as the central term and the six subsystem as the 2nd layer. The subsystems could be described and components of the subsystems could then be added. Using technology provides students with the opportunity to create a dynamic mind map where each item in this digital mind map could be digitally linked to a description, image, video, etc.

Content Knowledge

CK 2		Cognitive Process Dimension					
		Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Knowledge Dimension	Factual						
	Conceptual						
	Procedural						
	Metacognitive						

CK 2	*Learners are expected to ...*
	perform calculations involving translational speed, rotational speed, and torque.

Achievement Indicators

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

a describe, in qualitative terms, the relationship among speed, distance, and time for translational motion;

b perform calculations involving the relation among speed, distance and time for translational motion;

c describe, in qualitative terms, the relationship among rotational speed, number of revolutions, and time for rotational motion;

d perform calculations involving the relationship among rotational speed, number of revolutions, and time for rotational motion;

e describe, in qualitative terms, the relationship among torque, force, and lever arm length for rotational motion;

f perform calculations involving the relationship among torque, force, and lever arm length for rotational motion; and

g describe the effect of passive assistance on rotating joints.

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

Elaborations

Students may have used the terms speed, distance, time, and torque at various times. However, when speaking about speed in everyday language, we usually refer to forward (translational) speed. Students should be able to qualitatively describe these terms and the relationships among them. All quantities referenced in this specific curriculum outcome require the use and manipulation of three variable equations. It is important that students understand that these formulae, and the skills they need to learn in order to manipulate the formulae, develop from a fundamental understanding of the variables involved in the equations. For instance, to develop the relationship between speed-distance-time, students could be asked questions such as, "If you travel at 100 km/h, how far will you travel in 5 hours?" and "If you travel 200 km in 4 hours, what was your average speed?" Once the relationship between speed-distance-time is developed, students should be expected to manipulate and solve for any variable in the speed-distance-time formula (d=vt). Students must pay particular attention to the units of measure for speed so that corresponding variables (distance, time) are used with appropriate units.

Student could be asked to measure the actual forward speed of one of their robots using several trials over a fixed distance. It may be helpful to have students convert their speed value to another unit of measure and to consider which unit of measure may be most appropriate for communicating the speed of a robot in a classroom. For instance, cm/s may be easy to visualize for robots in a classroom; however, cm/s may not be appropriate for cars travelling on the Trans-Canada highway. Students should recognize that the unit of measure is important for communication as it is, to some extent, context sensitive.

In addition to forward speed, two important qualities are rotational speed and torque. Within the contexts of this outcome, students will develop an understanding of torque and rotational speed, the quantities involved, and the basic calculation of both quantities. Rotations per minute (rpm) can be used to report free speed. Torque can be calculated and reported as a N·m. Specific curriculum outcome CK3 will move students from a basic understanding of these quantities to an analysis of how gear ratio affects rotational speed and torque, and the connection between rotational speed and forward motion (translational speed). Furthermore, specific curriculum outcome PK4(d) provides students with an opportunity to test the effect of gear ratios on axle speed and torque through the construction and testing of a winch.

Content Knowledge

CK 3		Cognitive Process Dimension					
		Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Knowledge Dimension	Factual						
	Conceptual				■		
	Procedural						
	Metacognitive						

CK 3	*Learners are expected to ...*
	analyse power transmission problems involving gear ratios.

Achievement Indicators

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

a identify gear types (spur, rack, pinion, worm, bevel, idler, etc) and describe their function;

b describe the purpose of gears and sprockets in terms of their effect on gear ratio;

c describe the purpose of gears and sprockets in terms of their ability to change the direction or distance of power transmission;

d qualitatively analyse the relationship among gear ratio, axle speed, and axle torque for simple and compound gearing systems;

e perform calculations involving the relationship among gear ratio, axle speed, and axle torque for simple and compound gearing systems; and

f perform calculations to analyze the theoretical and actual speed of drivetrains containing simple and compound gearing systems.

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

Elaborations

Gears play an important role in controlling power transmission. Gears can change the direction of force, amount of force, and speed of rotation. To accomplish this, a variety of gear types are used. Students should be familiar with the following gear types, and their associated roles: spur, bevel, worm, rack, and idler.

In order to analyse problems involving gear ratio, students must first be aware of the meaning of "driving gear" and "driven gear," as well as the gear ratio reporting convention (driven gear size : driving gear size) expressed as a number-to-one (# : 1).

Note 1: Gear ratio always expresses the number of rotations of the drive wheel for every single rotation of the driven wheel ALTHOUGH rotations are not used in the formula… only gear circumference (typically in the unit of "teeth count"; driven gear size : driving gear size).
Note 2: Reduction ratio is a different ratio, opposite to gear ratio.

Prior to engaging in a quantitative analysis, students should be provided an opportunity to experience the effects of different gear ratios on speed and torque. Specific Curriculum Outcome PK4(d) suggests that students build and test a device containing multiple gear ratios. Another activity suggests that a robot be designed and built for the purpose of pulling a skid plate over a set distance in the shortest amount of time possible. These activities should provide students with a valuable context to draw upon when engaging in a quantitative analysis.

Students should be able to calculate the theoretical axle speed and torque (given motor speed and torque values) as a result of gear ratio. Furthermore, students are expected to identify whether there will be a speed increase and torque decrease (or vice versa) when the driven gear is larger (or smaller) than the driving gear.

Calculate the Axle Torque: Axle Torque = Motor Torque x Gear Ratio

Calculate the Axle Speed: Axle Speed = Motor Speed ÷ Gear Ratio

Furthermore, students should calculate the expected values of forward speed (translational speed) using motor free speed, gear ratio, and tire circumference and compare their results to the actual values obtained through experimentation. Reflecting on their speed data, and in considering of the chassis/drivetrain attributes, students should reflect on the role of continued testing in the development and improvement of prototypes.

Forward Speed (cm/s): $\text{Forward Speed} = \dfrac{\text{Axle Speed (RPM)} \times \text{Tire Circumference (cm)}}{60}$

Content Knowledge

CK 4		Cognitive Process Dimension					
		Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Knowledge Dimension	Factual						
	Conceptual		■				
	Procedural						
	Metacognitive						

CK 4	*Learners are expected to ...*
	describe how traction and turning are affected by friction.

Achievement Indicators

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

a describe the factors that affect friction (coefficient of friction ‘roughness’ and normal force);

b describe, in qualitative terms, how each factor that affects friction can be manipulated to increase or decrease the frictional force;

c explain when it is favorable/unfavorable to increase frictional force;

d define scrub torque; and

e describe factors that affect scrub torque (chassis geometry, mass distribution, coefficient of friction ‘roughness’, etc.).

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

Elaborations

Teachers could address achievement indicators CK4(a,b) by asking students how traction can be increased. From their discussion, the factors affecting traction may be identified and described. This activity would lead to an introduction to frictional forces and the two factors affecting friction (normal force and coefficient of friction 'roughness'). As an introduction to the two types of frictional forces (kinetic, static), students can be invited to comment on the amount of force required to move a stationary box from rest versus the amount of force required to keep the same box sliding at a constant speed. Consequently, students should be engaged in an activity that permits them to alter the stance, tire type, and the gear ratio of the drivetrain of a robot designed for the purpose of a "tractor pull" competition. As part of the competition, students could be asked to communicate the adjustments made to their robot in terms of traction. This outcome ties very closely to SCO CK3 (gear ratios), PK1 (collaborate), PK2 (communicate), and PK4 (assemble a device) which all contribute to the engineering design process which is necessary for the advancement of technology transfer. It is important that students develop an understanding of the importance of communication, collaboration, and partnerships in scientific and technological development.

Achievement indicators CK4(c,d,e) can be addressed by considering how friction plays an important role in determining the type of drivetrain, stance, and traction to use in a robot design. There have been numerous opportunities for students to experience tank-style steering (skid-steer) in this course via SCO PK4(b,c); however, they may not have explicitly tested the effect of altered drivetrain design (stance, wheel-base, load) on skid-steer type drivetrains. Furthermore, they should be provided with an opportunity to construct and test a chassis design containing a rear differential drivetrain with an articulating front-end steering mechanism as well as tank treads. Having tested each drivetrain type, students are expected to describe how turning scrub affects a robot's ability to turn, and how this quantity can be altered to minimize scrub.

Determining the most appropriate drivetrain, chassis design (stance), and traction is situationally dependent. Students are expected to analyse the design of a differential and skid-steer drivetrain and the way it functions with respect to its purpose, impact on everyday life, and safety.

Note on Engineering Design: Students should begin to evaluate various designs to determine which is best to address the criteria/constraints for the final project (SCO PK5 - Engineering Design). Students should begin to think about questions such as: "Should skid-steer or a differential design be used?"; "What geometry is conducive to maneuverability?"; "How can an object manipulation be added?"; and "Should tank treads or tires be used?".

Content Knowledge

CK 5	Cognitive Process Dimension					
Knowledge Dimension	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Factual						
Conceptual						
Procedural						
Metacognitive						

CK 5	*Learners are expected to ...*
	describe the design and interrelationship among object manipulators, rotating joints, and linkages used in mechanical systems.

Achievement Indicators

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

a describe the three degrees of rotational and translational freedom;

b describe the form and function of rotating joints and linkages, various types of object manipulators (plow, scoop, friction grabber), and the various types of accumulators;

c describe common designs of manipulator-rotating joint-linkage combinations used to manipulate objects.

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

Essential Graduation Competencies

Elaborations

Students should be exposed to various types of object manipulators, such as the plow, scoop, and friction grabber. To provide context, students should have the opportunity to assemble a robot containing one or more types of object manipulators (SCO PK4(c)). They should evaluate each type based on its design purpose and effectiveness. The real world application must always be considered when designing a manipulator. Questions to consider during the planning/design phase include:

- What orientation will the object be in when picked up?
- Does the gripper need to be able to grasp the object from multiple orientations?
- How will the gripper deposit the object?
- Does it need to deposit the object in multiple orientations?
- What orientation change does the object need to make between pickup and deposit?

The appropriate manipulator should be able to quickly and efficiently complete their tasks with minimum wasted motion and time.

Depending on the answer to the above questions, accumulator design may be considered to collect a large number of similar objects. Accumulators often use rollers or belts to collect objects. The accumulator itself may also serve as storage; however, other components can be added for storage such as sleeves or hoppers. Efficient accumulators collect objects quickly, store multiple objects, and are not prone to malfunction (jamming). Consequently, students must consider form and function of the physical components of the accumulator, how they interact with each other, and how they interact with the entire robot.

The robot should be designed to allow as little time to elapse as possible between picking up the object and storing it. Speed & Efficiency are critical!

Object orientation and efficiency of completing the task must always be considered when determining which manipulator type matches the task being performed. In addition to manipulator type, students are expected to describe the three basic types of degrees of freedom for both translational and rotational motion. Additional variables to consider when analysing joint/linkages/manipulator for form and function include: the weight of the objects to be manipulated; how high the arm needs to reach; and the size of the objects being manipulated.

Procedural Knowledge

PK 1		Cognitive Process Dimension					
		Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Knowledge Dimension	Factual						
	Conceptual						
	Procedural					■	
	Metacognitive						

PK 1	*Learners are expected to ...*
	collaborate with team members to assemble and design a device.

Achievement Indicators

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

a listen and ask questions to understand and appreciate the points of view of others;

b collaboratively plan, problem solve, and make decisions;

c demonstrate a positive attitude towards their work, instructors, and teammates;

d demonstrate a productive work ethic;

e demonstrate effective time management skills; and

f reflect on individual and group processes used in planning, problem solving, decision making, and completing a task.

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

Elaborations

Central to this course, and to most work environments, is the ability to collaborate effectively. Collaboration involves interpersonal skills, knowledge of group dynamics, the flexibility to work in teams, the ability to lead and to follow, problem-solve, and effectively communicate. The achievement indicators involved with this curriculum outcome are categorized as Planning - PK1(a,b), Execution - PK(c,d,e), and Reflection - PK1(f).

The first category of achievement indicators involves student planning, problem-solving, and decision making in a collaborative environment. It requires all members provide their own perspective and understand and appreciate the points of view of others. It requires speaking to articulate points of view, to ask clarifying questions, and to listening for understanding. Criteria should be created to permit groups to move from problem-solving to decision-making.

The next category of achievement indicators involves collaboration in executing a plan. This involves a positive attitude towards the work being performed and the people performing the work. It requires all members of a group working towards a common goal. Recognizing individual and group responsibilities and the importance of effective time management are key to the execution of a plan.

Communication and collaboration are important skills that need to be developed; consequently, frequent assessment of these skills should occur throughout this course with opportunity for feedback and improvement. This can occur in a variety of ways such as assessment checklist, self- and peer- assessment, reflective journals, or formal/informal interviews. The weighting of the assessment data should progressively increase (move from more formative to more summative) as the course continues. For these processes to be effective, groups should adopt a set of "Norms for Collaboration". Considering the nature of this course, these norms should be co-constructed by the students and teacher. The teacher could assess the criteria several times for each reporting period and use this cumulative data to evaluate student performance of this outcome.

The final achievement indicator related to collaboration emphasizes reflection. Students should be provided with an opportunity to reflect upon their performance against a set of success criteria. Their reflection can be captured in a journal or another appropriate format.

Procedural Knowledge

PK 2		Cognitive Process Dimension					
		Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Knowledge Dimension	Factual						
	Conceptual						
	Procedural						
	Metacognitive						

PK 2	*Learners are expected to ...*
	communicate ideas, plans, results, and concepts using appropriate numeric, symbolic, graphical, and linguistic modes of representation.

Achievement Indicators

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

a express ideas, information, and learnings considering purpose and audience;

b engage in effective and responsible communication while brainstorming for possible solutions to a challenge or problem;

c communicate the results of a scientific or technological endeavour, using appropriate language and technical writing conventions;

d communicate design concepts through technical drawings, models, digital images, or other appropriate forms;

e understand and avoid plagiarism; and

f revise their writing to improve communication of the message.

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

Elaborations

The emphasis of communication in the context of this specific curriculum outcome is on the output of information/ideas (writing and speaking) as opposed to input (reading and listening). Achievement indicators PK2(a,b) involves the communication of information, ideas, and plans while working in a group setting.

Considering the highly collaborative nature of this course, indicators PK(a,b) should be addressed and assessed frequently. Consequently, teachers may wish to engage students in a process of co-constructing criteria surrounding the communication side of collaboration. Criteria could be developed by answering the question, "What matters, what counts, and what is important when communicating in a group setting?" These two achievement indicators integrate well with curriculum outcome PK1 (Collaboration). Teachers may consider including these indicators in the structure of the criteria developed for the "Norms of Collaboration" described in curriculum outcome PK1.

Achievement indicators PK(c,d) involve the technical aspect of communicating in science. 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 SCO PK2 is the quality or clarity of writing based on criteria such as word choice, organization, fluency, and mechanics. Students will be required to demonstrate their learning of curriculum outcome PK2(c,d,e,f) while addressing the project work involved in this course. A gradual release of responsibility model can be employed. For example, to develop proficiency with technical writing, this outcome can be scaffolded to provide students with opportunities to read and understand information in a variety of forms (technical drawings, models, digital images, or other appropriate forms). Once they have seen and understand examples of quality and proficiency they can be asked to practice using appropriate language and technical writing conventions with sets of given data. They can then graduate to working independently with their own authentic data.

Achievement indicator PK2(a,c,d) can also be addressed by having students maintain an Engineering Notebook. This notebook could be used by for students to keep their notes for a particular concept that they read about. The notebook could also be a place for students to connect the robot build to the content being learned (see specific curriculum outcome PK4). They could be asked to reflect upon, and answer questions related to, the big ideas and key questions tieing the theoretical and practical components of this course. The Engineering Notebook could take on several forms. Considering the frequency of use and importance of this notebook, teachers should provide, or co-create with students, the format and writing style that should be employed.

Procedural Knowledge

PK 3		Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Knowledge Dimension	Factual						
	Conceptual						
	Procedural			■			
	Metacognitive						

Cognitive Process Dimension

PK 3	*Learners are expected to ...*
	measure quantities and perform measurement conversions.

Achievement Indicators

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

a recognize the System International (SI) of measurement as the universal system of measurement;

b identify metric units of measure for variables related to speed, distance, time, mass, force, and torque;

c estimate measurement data for variables related to speed, distance, time, mass, force, and torque using common references;

d collect accurate measurement data for variables related to speed, distance, time, mass, force, and torque using appropriate measurement tools; and

e convert between metric units of measurement.

Essential Graduation Competencies

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

Elaborations

Students are expected to identify basic units for mass, distance, time, and force. They should also have a common reference to visualize the magnitude of these measurements. For instance, a meter is approximately the distance from a floor to a door knob; a second is approximately the time it takes to state “one-thousand-one”. Furthermore, students should be able to recognize units that describe torque (N·m) and speed (m/s, cm/s, km/h, etc) and also have a common reference for these quantities (1 m/s - speed of a basics direct-drive robot chassis; 3 n·m - torque applied by a vex motor).

Students are expected to know the meaning of the following metric prefixes: milli, centi, and kilo. They should be able to use all metric prefixes, given a table of prefixes, to convert between units of measurement mentally. These conversions would involve restating a metric measurement with a new prefix and altering the numeric component of the measurement by shifting the decimal. Students should understand that restating a measurement with a prefix of larger magnitude requires an adjustment to reduce the numeric component of the measurement by the same factor, and vice-versa.

Note: Caution should be considered when using dimensional analysis as students may become experts in using this method to obtain the correct answer without knowing why or how the answer is obtained. Students should be aware that multiplying by a reciprocal is equivalent to dividing. It is suggested that students be first introduced to conversions that are easily performed mentally such that they can not only observe how dimensional analysis works but also why it works. For example, students could be asked how many kilometres is 5000 metres. Mental Math: Knowing that there are 1000m in 1 km, one should wonder how many times 1000 goes into 5000 ... Divide 5000 by 1000 yields 5 km.

The process of dimensional analysis always begins by creating an equation where the desired measurement equals the given measurement multiplied by a conversion factor, or series of conversion factors. It is recommended that the students create a "metric staircase" which illustrates the relation between metric prefixes from milli to kilo. This graphic analogy should assist students in determining how to set up the equation which contains the conversion factor that ultimately multiplies or divides the given measurement in order to make the equation true.

Procedural Knowledge

PK 4		Cognitive Process Dimension					
		Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Knowledge Dimension	Factual						
	Conceptual						
	Procedural						
	Metacognitive						

PK 4	*Learners are expected to ...*
	assemble and analyse the design of a device, and troubleshoot problems as they arise.

Achievement Indicators

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

a interpret technical drawings and specifications to assemble a device;

b assemble a basic four-wheel drive chassis and analyse its function, including style of drive (tank, arcade, etc.);

c assemble a chassis containing an object manipulator and analyse its function, including the manipulator (plow, scoop, friction grabber, accumulator), rotating joints, and linkages.

d assemble a device containing multiple gear ratios and analyse its function, including the effect of gear ratio on rotational speed and torque;

e assemble a device containing a differential with articulating steering and analyse its function, including the advantages/disadvantages of this design;

f assemble a device containing a tank tread and analyse its function, including traction, friction, and turning scrub (scrub torque); and

g assemble a device using an appropriate gear ratio, traction, and weight distribution to efficiently haul a skid plate.

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

Elaborations

This course may provide the first opportunity for many students to construct a robot, or a device, from a schematic diagram. Prior to assembly, students should have had the opportunity to address CK1 (Robot Subsystems) and a lesson on reading schematic diagrams - PK4(a). In order to ensure exposure to proper design techniques and to help them with assembly, students should first be provided with explicit instructions and schematics as related to PK4(b,c,d,e,f). The first robot construction will consist of a basic square chassis design involving arcade-style (single joystick) and tank-style (dual joystick) control. Constructing this basic robot should provide students with an opportunity to develop an operational understanding of robot subsystems, the basic components of the sub-systems, and how the sub-systems function as a unit. This first build also provides students the ability to work on team dynamics - assigning a group task, sharing team responsibilities, and troubleshooting problems as they arise. Consequently, it is recommended that teacher address, in part, PK1 (collaboration) and PK2(a,b) prior to the first build so students are familiar with norms of collaboration and have had the opportunity to engage in team building exercises.

While addressing PK4(c), teachers should be aware that students have experience in the assembly of a basic robot chassis with arcade- and tank- style drive systems. Students are now expected to build on this prior learning by creating a robot containing an arm assembly with a gripper for object manipulation. It is expected that students be provided with explicit instructions and diagrams to assist in the construction so that they continue to have exposure to proper design techniques. Please Note: Limit/Bumper switches should have been introduced with CK1 (Subsystems). Consequently, students should incorporate limit switches in their robotic arm designs to prevent damage to motors (dead stops) and other robot components. This outcome should precede CK5 (rotating joints, linkages, manipulators).

In addition to continued reinforcement of reading schematic diagrams and a general understanding of design, achievement indicators PK4(c,d,e,f) should precede addressing associated content knowledge (CK) outcomes. By providing an opportunity for students to assemble and test a variety of designs, they begin to develop contexts and operational understandings that can be drawn upon to develop content knowledge and the processes of scientific literacy (inquiry, problem solving, decision making). Consequently, achievement indicators PK4(d,e,f) should be strategically addressed to support specific curriculum outcomes CK3 (Gear Ratios) and CK4 (Traction/Turning).

Both the assembly and the analysis component of specific curriculum PK4 must be assessed. For each build, a robotic construction and functioning rubric should be provided to assess how well the robot was built in relation to the technical drawings provided. The functioning of the robot should also be included in the rubric criteria. Furthermore, the analysis component of this outcome could be assessed by having students reflect upon, and answer questions related to, the big ideas and key questions related to each build, preferable connected to all components of STEAM. These questions could be isolated in an independent assignment or included in an Engineering Notebook (see specific curriculum outcome PK2).

Procedural Knowledge

PK 5		Cognitive Process Dimension					
		Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Knowledge Dimension	Factual						
	Conceptual						
	Procedural						■
	Metacognitive						

PK 5	*Learners are expected to ...*
	create a device to perform a simple task using an engineering design process.

Achievement Indicators

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

a describe the components of an engineering design process;

b identify the problem/challenge, design criteria, and design constraints within a given challenge;

c engage in effective and responsible communication while brainstorming and researching for possible solutions to a provided challenge or problem with consideration to the design criteria/constraints;

d 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;

e communicate design concepts through technical drawings, models, digital images, or other appropriate forms;

f design and assemble a prototype of a device to perform a simple task;

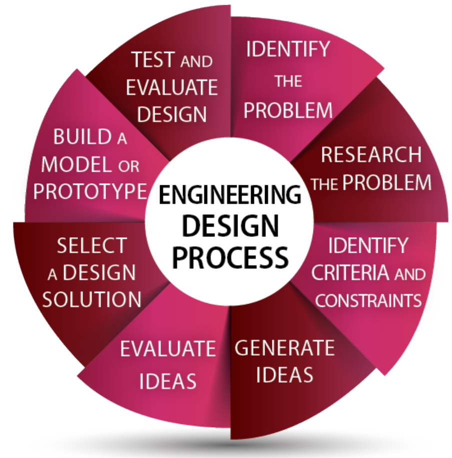
g test and evaluate the effectiveness of a prototype to perform a task according to criteria and constraints; and

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

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

Elaborations

The intent of PK5 is to have students groups engage in a culminating final project that integrates their knowledge, skills, and processes obtained throughout this course from all four foundations of science literacy.



The groups can be provided with a class challenge/competition or individual groups may identify a challenge that only their group will engage in. It is recommend that design criteria and design constraints be co-constructed. When designing and building any device it is important to clearly identify the purpose of the design, research existing designs, evaluate prototypes, and consider other relevant variables. Students should be expected to identify, describe, and engage in the components of an engineering design process. Although the components of an engineering design process may vary from source to source, they usually include a version of the following components: (a) identifying the problem; (b) conducting research; (c) identifying criteria and constraints; (d) generating ideas; (e) evaluating ideas; (f) selecting a design solution; (g) building a model or prototype; and (h) testing and evaluating.

Student groups should be provided with the autonomy to create a unique design. Teachers are encouraged to facilitate the process by having students reflect on the design principles they have learned and continuously evaluate their design for its effectiveness in accomplishing the prescribed task. The final project will involve team members working cooperatively to design, assemble, and test a robot design using components appropriate for completing a predetermined task. This process will involve the consideration of alternative solutions and the identification of potential strengths and weaknesses of each.

Assessment of this project should be multifaceted, and opportunities to involve the students in co-constructing assessment criteria is encouraged. Robots should be assessed based on their effectiveness in completing the assigned tasks. The design of the robot should be assessed in accordance with a chassis and component construction rubric. Furthermore, student teams should be assessed on the engineering design process related to the research, design, and assembly of major components (chassis, drivetrain, manipulator, etc) of the final product. It is recommended that the assessment of the engineering design process occur while the project is under way. It is expected that student teams develop a slideshow presentation that documents the engineering design process they used. Students should be provided with the presentation criteria/rubric for assessing the presentation of their final product.

Considering the time required to complete this task as well as the complexity of engaging in an authentic process, considerable time will be spent collaborating and communicating; consequently, frequent assessment (self, peer, teacher) of specific curriculum outcome PK1 (Collaboration) and PK2 (Communication) should be considered.

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

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

Literacy Strategies that Support Science Learning

Speaking and Listening

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

Reading and Viewing

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

Writing and Representing

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

Assessment Literacy

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

Vocabulary

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

Appendix C: Characteristics of TOS Assessment Levels

Assessment items can be classified according to three levels of complexity. Characteristics of each level are provided with examples in the following table. The verb examples provided are described within the context of Applied Science 701A.

Level 1—Remembering and Understanding (Low Complexity)		
Level 1 items rely heavily on recall, recognition and understanding. These items typically specify what the student is to do.	• **Identify** … to establish what something is • **Define** … to provide the definition • **Describe** … to give an account of something	• **Explain** … to give a reason for • **Recognize...** to identify from having encountered before • **Understand** … to perceive intended meaning
Level 2—Application and Analysis (Moderate Complexity)		
Level 2 items offer more flexibility of thinking and choice. They require a response that goes beyond the habitual and ordinarily has more than a single step. The student is expected to decide what to do using informal methods of reasoning and problem-solving strategies. Students are required to bring together skills and knowledge from various domains.	• **Assemble...** to fit together separate component parts of a device • **Perform** … to carry out or execute a task • **Communicate** … to share or exchange information • **Engage** … to participate or become involved in a task • **Express** … to convey using words, symbols, or gestures	• **Revise**… to re-examine and make alterations • **Analyse** … to methodically examine the components of something in order to explain or interpret • **Measure** … to use a device to ascertain the size or amount • **Collect** … to gather together • **Estimate** … to roughly calculate or judge the value
Level 3—Evaluating and Creating (High Complexity)		
Level 3 items placed heavy cognitive demands on students by requiring them to engage in reasoning, planning, analysis, judgement and creative thought. Students must think in an abstract and sophisticated way.	• **Evaluate** … to assess the value of something • **Design** … to create or fashion something novel • **Collaborate**… to work with others for the purpose to evaluate and/or create	• **Create** … to bring something novel into existence • **Reflect**… to think deeply and carefully about • **Argue...** give reasons or cite evidence in support of an idea or claim

Glossary

A

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

C

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

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

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

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

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

D

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

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

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

E

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

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

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

F

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

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

H

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

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

I

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

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

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

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

L

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

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

M

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

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

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

O

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

P

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

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

Q

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

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

R

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

S

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

scientific study - scientific investigation or research.

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

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

system dynamics - the nonlinear behaviour of complex systems over time.

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

T

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

V

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

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