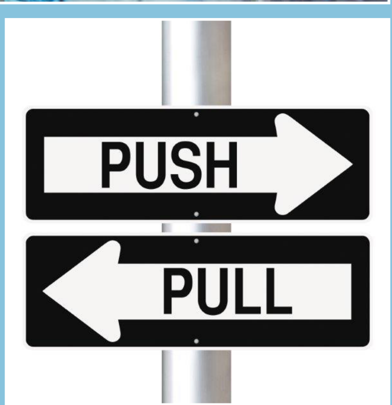
SCI421A

SCIENCE

GRADE 10



Curriculum Guide

Prince Edward Island
CANADA

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Introduction

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.

Purpose of Curriculum Guide

The overall purpose of this curriculum guide is to advance social studies education through teaching and learning, and, at the same time, recognize and validate effective practices that already exist in many classrooms. More specifically, this curriculum guide

- provides detailed curriculum outcomes to which educators and others can refer to when making decisions concerning learning experiences, instructional techniques, and assessment strategies for the social studies program;
- informs both educators and members of the general public about the philosophy and scope of social studies education for the senior high school level in Prince Edward Island;
- promotes the effective learning and teaching of social studies for students.

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.

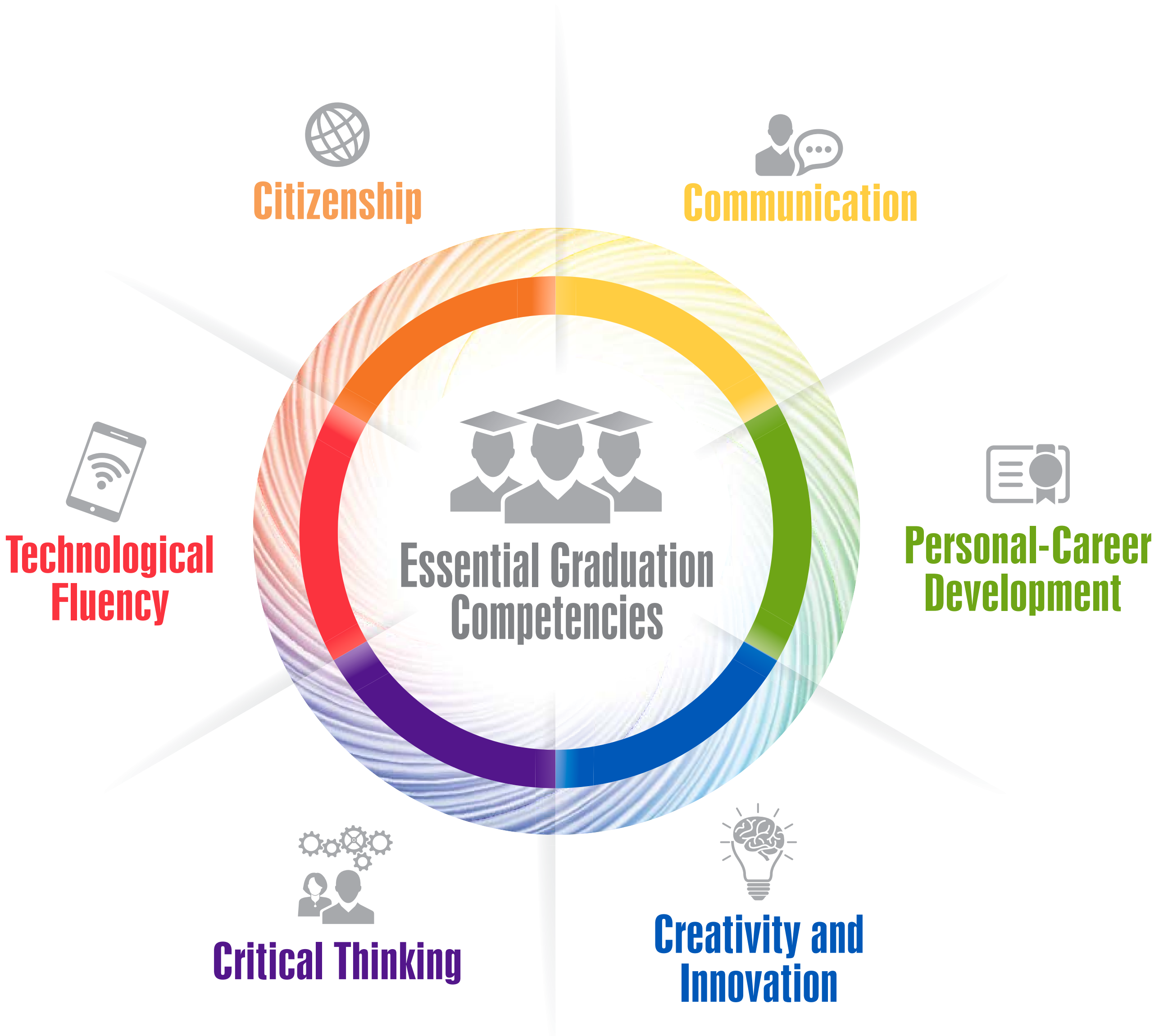

Figure 1. *Essential Graduation Competencies*

Curriculum Design

Essential Graduation Competencies—Definitions

Critical Thinking

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

Learners are expected to

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

Technological Fluency

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

Learners are expected to

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

Curriculum Design

Citizenship

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

Learners are expected to

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

Communication

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

Learners are expected to

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

Curriculum Design

Personal-Career Development

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

Learners are expected to

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

Creativity and Innovation

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

Learners are expected to

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

Foundations of Scientific Literacy

PEI science curriculum is based upon four foundations deemed essential to scientific literacy. Three of these components–Procedural Knowledge, Content Knowledge, and Decisions and Perspectives–reflect 1) the processes and skills required in the development and application of scientific knowledge, 2) the resulting body of knowledge, and 3) the need for critical thinking about the application of science developments from a variety of perspectives and with consideration of ethics. Central to these three foundations is the Nature of Science, which addresses epistemic knowledge or the principles underlying science as a way of knowing. More detail relating to these concepts can be found in the section “Foundations of Scientific Literacy” p.22. The foundations of science literacy support and are integrated with the six essential graduation competencies.

Figure 2. *Nature of Science*

General Curriculum Outcomes

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

Nature of Science (NoS)

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

Procedural Knowledge (PK)

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

Content Knowledge (CK)

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

Decisions and Perspectives (DP)

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

Curriculum Design

Specific Curriculum Outcomes

Specific curriculum outcomes (SCOs) identify what students are expected to know and be able to do for a particular course. They provide a focus for instruction in terms of measurable or observable student performance and are the basis for the assessment of student achievement across the province. PEI specific curriculum outcomes are developed with consideration of Bloom's Taxonomy of Learning and the Essential Graduation Competencies.

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

Achievement Indicators (AIs)

Each specific curriculum outcome is described by a set of achievement indicators that support, define, and demonstrate the depth and breadth of the corresponding SCO. Taken together as a set, AIs support the SCO in defining specific levels of knowledge acquired, skills applied, or attitudes demonstrated by a student for that particular outcome.

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

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

Elaborations

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

Curriculum Design

Bloom's Taxonomy

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

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

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

Cognitive Process Dimension

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

Table 1. Bloom's Taxonomy—Cognitive Process Dimension

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

Curriculum Design

SCO Structure

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

verb: explain
cognitive process: UNDERSTANDING

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

Curriculum Guide Layout

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

Table 2. Details of Curriculum Guide Layout

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

Curriculum Design

Name of Curriculum Unit

Specific Curriculum Outcomes (SCOs)

Nature of Science

Specific curriculum outcome (SCO)

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

Cognitive process level for this particular SCO

Achievement Indicators

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

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

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

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

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

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

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

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

Essential Graduation Competencies Map

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

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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" on page 9). The achievement indicators inform teachers of the depth and breadth of skills, knowledge, and understandings expected for each SCO.

Assessment has three interrelated purposes:

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

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

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

Effective assessment strategies

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

Science Learning Environment

Social and Emotional Learning (SEL)

Social and emotional learning is the process through which children and adults acquire and effectively apply the knowledge, attitudes, and skills necessary to understand and manage emotions, set and achieve goals, feel and show empathy for others, establish and maintain positive relationships, and make responsible decisions (Weissberg & Cascarino, 2013).

The benefits of social and emotional learning (SEL) are well-researched. Evidence demonstrates that an education integrated with SEL yields positive outcomes for students, adults, and school communities. These findings include increased social and emotional skills, academic performance, mental wellness, healthy behaviours, school climate and safety, and positive lifetime outcomes (Durlak et al., 2011).

Students will experience a sense of belonging and emotional safety when teachers develop a supportive atmosphere where students feel valued and are encouraged to express their ideas and emotions. While SEL isn't a designated subject like history or math, it must be woven into a school's curriculum and community (Durlak et al., 2011; Wiglesworth et al., 2016). The following five skills provide examples of how social-emotional learning competencies can be incorporated into the curriculum:

Self-Awareness entails the understanding of one's own emotions, personal identity, goals and values. Integrating self-awareness involves planning activities and practices that help students understand and connect with their thoughts, emotions, and strengths and how they influence behaviour;

Self-Management entails skills and attitudes that help students to regulate emotions and behaviours. Integrating self-management involves developing students' organizational skills, resilience, and goal-setting abilities through structured activities, personalized learning plans, and providing consistent feedback;

Social Awareness entails recognizing the perspective of those with the same or different backgrounds and empathizing and feeling compassion. Integrating social awareness involves incorporating diverse perspectives, cultural contexts, and collaboration while encouraging students to understand and appreciate the broader societal implications of the content they are learning;

Relationship Skills entail the tools to establish and maintain healthy relationships and effectively navigate settings with different social norms and demands. Integrating relationship skills involves fostering collaborative projects, encouraging effective communication and teamwork, and enabling students to develop positive interpersonal connections that enhance their learning experience and

Responsible Decision-making entails the knowledge, skills and attitudes to make caring and constructive choices about personal behaviour and social interactions across diverse settings. Integrating responsible decision-making within lessons involves incorporating real-world scenarios, ethical considerations, and critical information analysis to make thoughtful choices.

Supporting English as an Additional Language (EAL) Learners

Multilingual learners add valuable experiences to the classroom. The linguistic knowledge and experiences of English as an additional language (EAL) students can extend the understanding of the linguistic diversity of all students. When the language, prior knowledge, and culture of EAL students are valued, respected, and incorporated into learning, the learning environment is enhanced.

Supportive learning includes classroom practices that affirm cultural values and leverage students' home language and prior knowledge. Making connections to content and language structures in their home language and English is encouraged when possible. It is also essential that EAL students make connections between their learning in English and learning in other curricular areas and use learning contexts in other subjects to practice, reinforce, and extend their language skills. Addressing the demands of the subject area and discussing how different forms, styles, and registers of English are used for various purposes will benefit students. Providing students learning English as an additional language with ample opportunities to use English in communicative ways and designing classroom activities to aid language development through active language use will support their learning.

It's essential to address barriers to equitable instruction and assessment for EAL students. By providing various ways for them to access content, demonstrate learning, and develop language skills, we can ensure their full participation and contribution to the classroom community. This approach not only benefits EAL students but also enhances the overall learning environment.

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 3. 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

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.

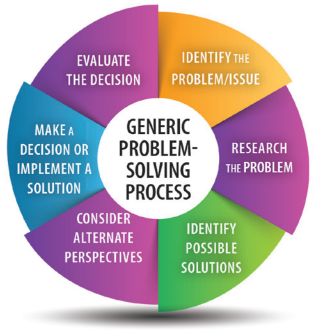


Figure 3. *Generic Problem-solving Process*

Figure 4. *Comparison of STEAM Problem-solving Processes*

Science Learning Environment

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.*

Data Collection and Analysis

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

Visualization and Imaging

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

Communication and Collaboration

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

Language Skills

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

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

Figure 5. *The Nature of Language Arts*

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

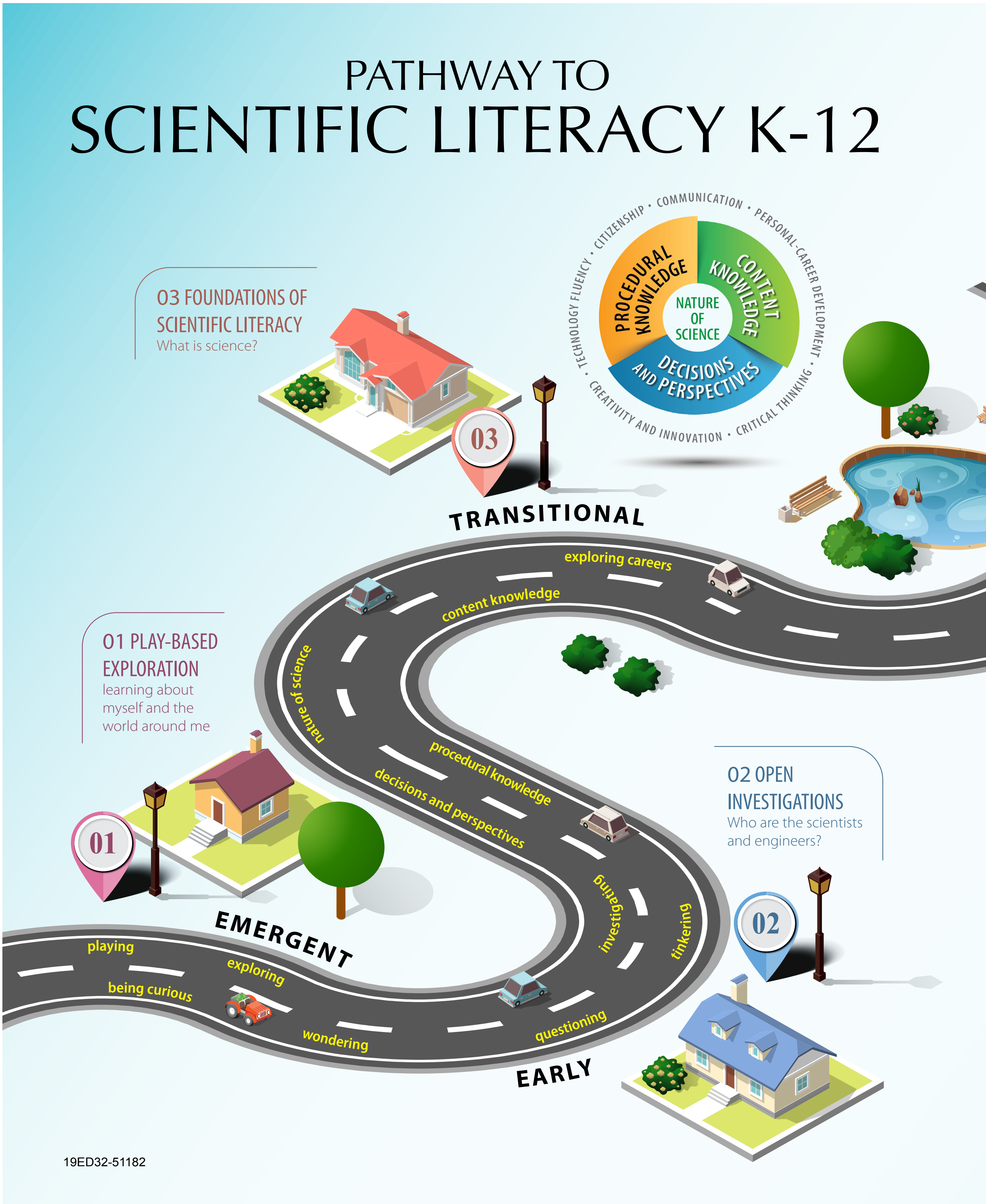


Figure 6. *Pathways to Scientific Literacy*

Pathway to Scientific Literacy

Overview

The four foundations of scientific literacy represent the complex and dynamic relationship of science and society that is depicted in Figure 7. 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.

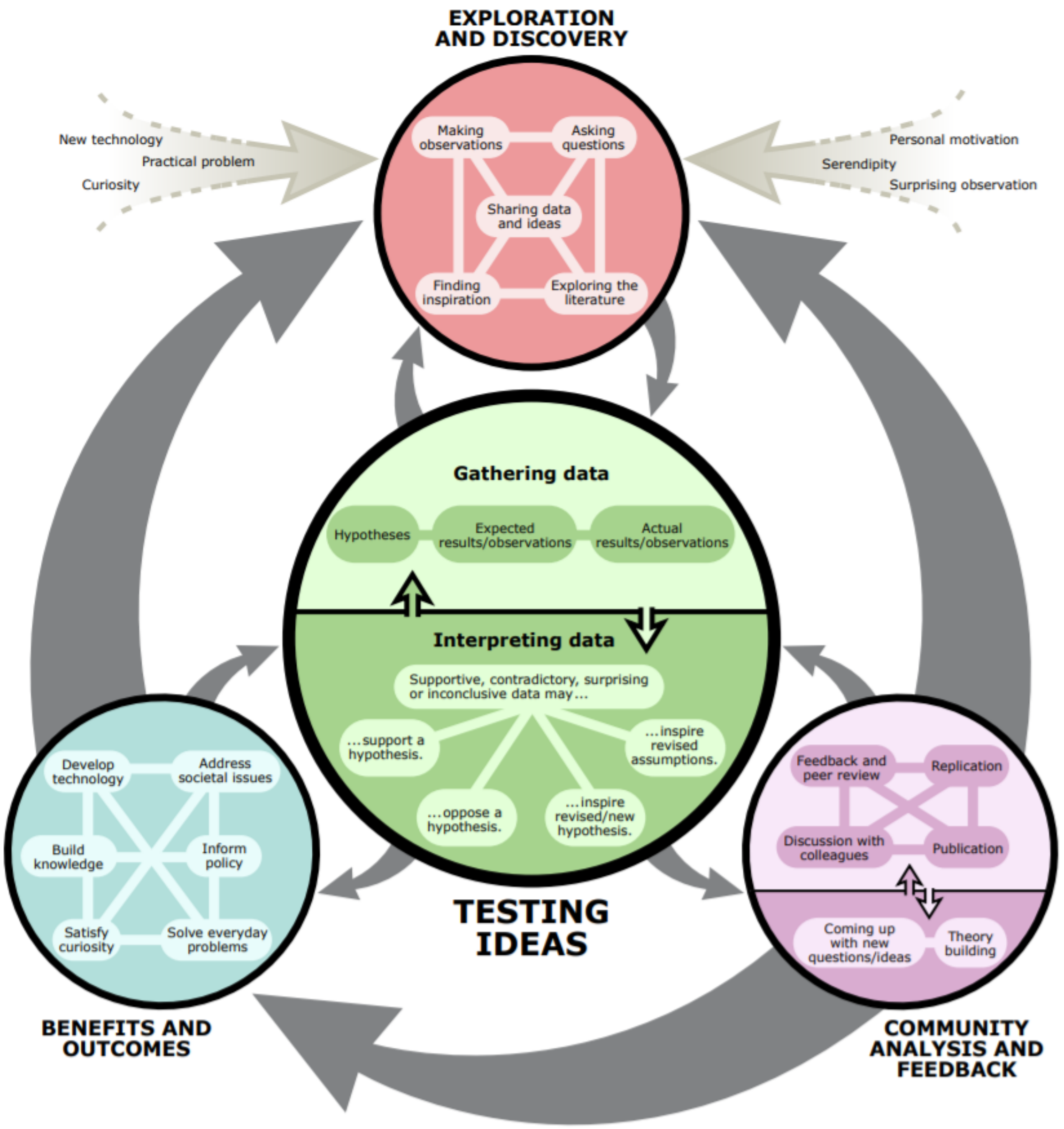


Figure 7. *How Science Works (University of California Museum of Paleontology 2016)*

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 9), 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?

Foundations of Scientific Literacy: Nature of Science

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

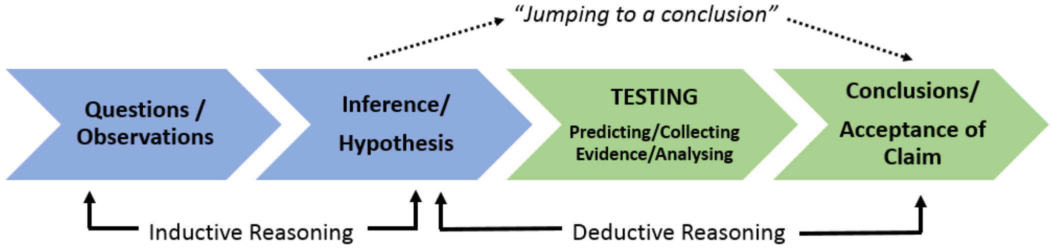


Figure 8. *Scientific Reasoning*

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

Foundations of Scientific Literacy: Nature of Science

- 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

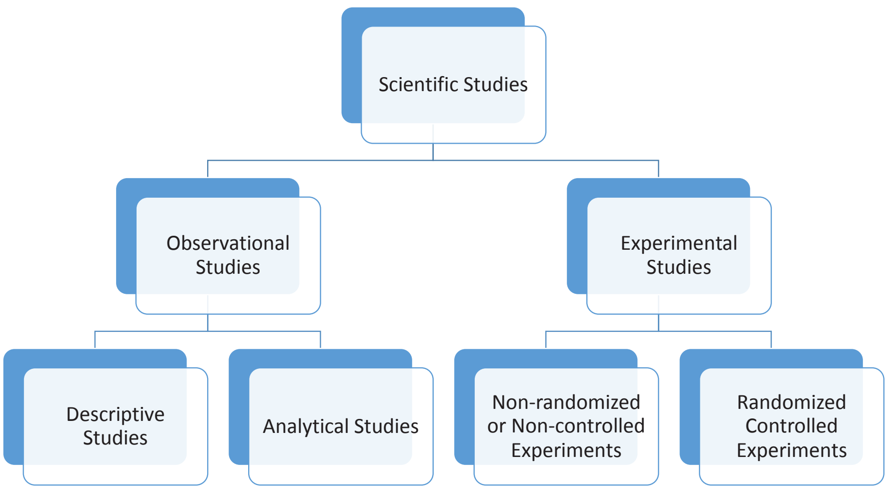


Figure 9. *Classification of Scientific Studies. Adapted from Oleckno, 2002*

Foundations of Scientific Literacy: Procedural Knowledge

Components of Scientific Inquiry

The process of developing scientific knowledge is a complex interplay of experimentation; current knowledge; modification of theories; debate; social, cultural, political, and economic influences; and peer review and acceptance. This observation of science has often resulted in the declaration, "There is no one scientific method." This statement is true in the sense that there are many ways to inquire or answer scientific questions, but it has seemingly resulted in a misconception in science education that the approach to scientific investigation is vague and that there are no common elements in the way that scientists inquire. While study designs (Figure 9) vary depending on the question being asked, the process of developing new scientific knowledge always involves a number of aspects or stages (Figure 10). 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

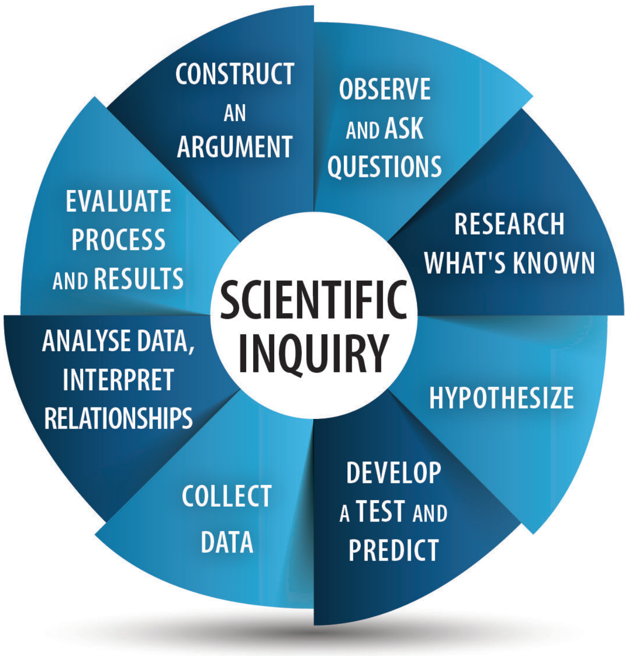


Figure 10. *Scientific Inquiry Process Wheel*

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 11)*
- *flow charts that depict energy flow in a food web (Figure 12) or electricity transmission rates (Figure 13)*

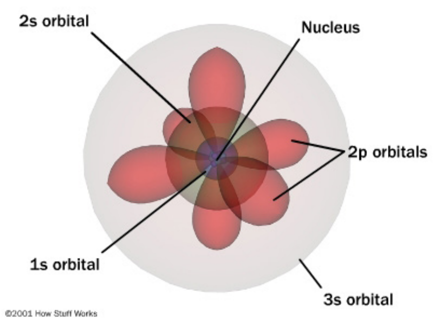


Figure 11. *Quantum Mechanical Model of the Atom*

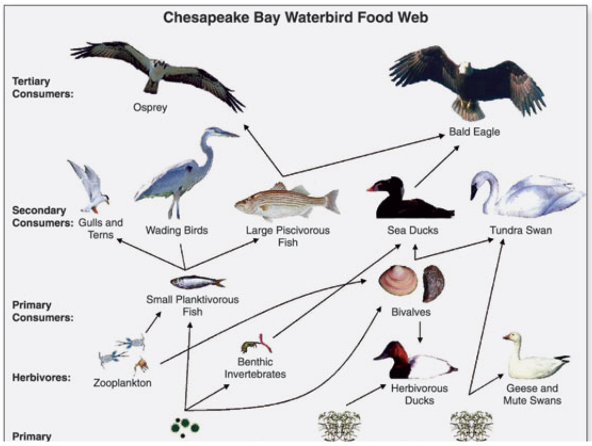


Figure 12. *Energy Flow in a Food Web (Perry 2019)*

Foundations of Scientific Literacy: Procedural Knowledge

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.

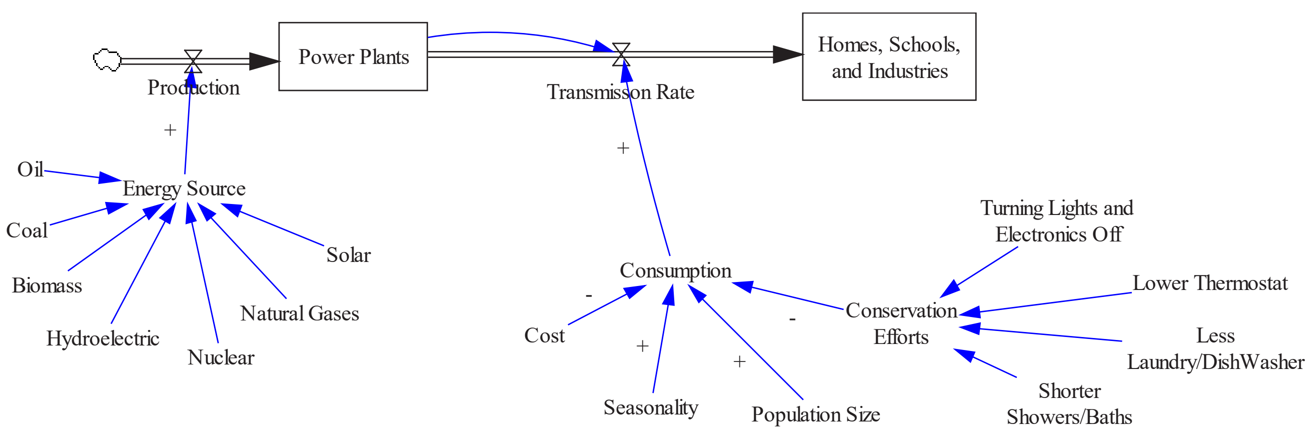


Figure 13. *Stock and Flow Conceptual Model*

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.26. 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.27). 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.

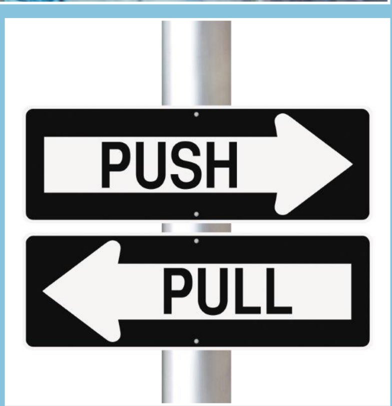
Decisions that we are required to make vary from personal day-to-day decisions to complex ethical issues that can affect entire species, including our own. As individuals, we make daily choices regarding food, health, and energy, often basing them upon scientific understanding. For example, studies on 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.

SCI421A

SCIENCE

GRADE 10



Curriculum Guide

Prince Edward Island
CANADA

Grade 10 Science 421A

Course Overview

For most learners, Science 421A marks the end of the transitional stage of scientific literacy (Figure 4 p.14). At this point, individuals will have a foundational understanding of science and recognize it as a reliable process of developing knowledge about the natural world. Some students will continue on to formally study science. For others, Science 421A will mark the end of their formal science education. It is essential that by the end of this course both groups of students reach a level of scientific literacy that will enable them to critically evaluate and make well-informed decisions regarding science-related claims, issues, and applications. These decisions include those involving food choices, health treatments, purchases, energy consumption, the environment, and career pathways. By this stage of development, students should have develop the habit of mind to pause for skeptical reflection when hearing purportedly science-based claims made in the mass and social media.

The development of scientific literacy is a function of the kinds of tasks and the discourse in which students participate. A hands-on, minds-on approach will engage students and encourage creativity, innovation, and problem-solving skills as students apply science to design and build their own creations. At the same time, it will encourage learners to recognize that science is not only a body of knowledge but a process of understanding and reasoning. Competencies such as critical thinking and citizenship will be fostered when students examine and debate topics such as pseudoscience, causal illusion, pandemics, and risks and benefits of the application of science.

In this curriculum guide, the specific curriculum outcomes are not arranged according to textbook units. This design is used to shift the focus away from a primary emphasis upon science topics or content, towards scientific literacy as defined by the four identified foundations: Nature of Science, Procedural Knowledge, Content Knowledge, and Decisions and Perspectives. Seventeen specific curriculum outcomes (SCOs) within these four foundations are used to identify the skills, knowledge, and understandings that students are expected to develop and/or deepen (Table 5 p.40). Seven questions that are intricately linked to these outcomes should be interwoven within instructional activities throughout the course. These questions link Science 421A to earlier grades:

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

Traditional “content” in science education consists of the scientific explanations (theories) regarding concepts such as structure, function, change, and causal relationships that the process of science has revealed. Content remains an integral part of this course but is viewed as the context through which “science” is learned. The three topics identified as context for Science 421A are Cells and Infectious Disease (life science), Real World Chemical Reactions, (physical science—chemistry), and Designing Mechanical Systems (physical science—physics). To demonstrate their understanding of these topics, students are expected to not simply state and recall facts, but to develop conceptual understanding, and apply their understanding to solve and analyze contextualized problems. They should also be able to make connections between the specific details of what they are learning to the broad interdisciplinary concepts ("Interdisciplinary Concepts" on page 26).

Grade 10 Science 421A

Outcome Summary

Table 5. Summary of Curriculum Outcomes

GCO	Code	Specific Curriculum Outcome
Nature of Science	NoS 1	Evaluate if a reported idea or claim is scientifically reasonable.
	NoS 2	Analyze factors that influence decisions to accept scientifically unreasonable claims.
Procedural Knowledge	PK 1	Synthesize information from reliable sources to extend understanding of scientific concepts.
	PK 2	Compose written arguments which effectively communicate scientific reasoning.
	PK 3	Design and evaluate a scientific investigation which examines a cause and effect relationship.
	PK 4	Create a machine that utilizes several transfers of energy to perform a simple task.
	PK 5	Perform investigations that examine the microscopic structure of cells, chemical reactivity, and the relationship between energy, forces, and matter.
	PK 6	Analyze data to determine patterns, trends, and causal relationships.
Content Knowledge	CK 1.1	Explain why the cell is considered a living system and responsible for the continuity and diversity of life.
	CK 1.2	Understand the transmission and prevention of infectious disease and anaylse its impact on society.
	CK 2.1	Predict the products of chemical reactions.
	CK 2.2	Analyze real world chemical reactions by applying the principles of chemical reactivity.
	CK 3.1	Apply the relationship between mass, force, and acceleration of objects.
	CK 3.2	Analyze energy transformations in mechanical systems.
Decisions and Perspectives	DP 1	Argue for or against the application of a scientific or technological development while demonstrating respect for the perspectives of others.
	DP 2	Demonstrate skills and characteristics necessary for career pathways related to science, technology, engineering, or math.

Assessment Framework

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

Table 6. Assessment Framework for SCI421A

Domain/GCO	Remember	Understand	Apply	Analyse	Evaluate	Create	GCO Weight
Nature of Science					NoS1		**10%**
				NoS2			
Procedural Knowledge						PK1	**30%**
					PK2		
					PK3	PK3	
						PK4	
			PK5				
				PK6			
Content Knowledge		CK1.1					**50%**
		CK1.2		CK1.2			
			CK2.1				
				CK2.2			
			CK3.1				
				CK3.2			
Decisions & Perspectives					DP1		**10%**
			DP1				

Reporting Structure

Nature of Science, Decisions & Perspectives	7	(10% of 70)
Procedural Knowledge	21	(30% of 70)
Content Knowledge	35	(50% of 70)
Decisions & Perspectives	7	(10% of 70)
Major Assessments	30	(Reflective of Domain Weightings)

Nature of Science

NoS 1	*Learners are expected to ...*					
	evaluate if a reported idea or claim is scientifically reasonable.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
					■	

Achievement Indicators

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

a use the following vocabulary appropriately: argument, bias, claim, evidence, falsify, scientific reasoning,bias, causal illusion, confirmation bias, correlation, causation, cause and effect, blind, double-blind;

b describe the role of experimentation, collecting evidence, finding relationships, proposing explanations in the development of scientific knowledge;

c explain the interplay among inductive and deductive reasoning as part of scientific reasoning.

d evaluate if the argument supporting the claim is based on scientific principles and reasoning such as it

- *is based on testing and data that has been verified by others,*
- *is a valid interpretation of the data,*
- *is supported by multiple lines of evidence,*
- *uses sufficiently large data sets and sampling procedures,*
- *describes the experimental controls if appropriate,*
- *considers weakness in the argument such as possible confounding variables,*
- *is reasonable in consideration of well-established scientific "facts",*
- *is logical,*
- *is able to be falsified;*

e distinguish between examples of correlational and causal relationships; and

f conclude, with justification, if a reported idea or claim is scientifically reasonable. (links to PK 2, DP 1)

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

ELABORATIONS

During Grade 9 Science students were introduced to indicators that the novice can use to make decisions about the validity of what they are viewing. These include word choices, tone, source, and the type of publishing medium. In this course the reasonableness of the scientific claim will be judged by the students on the strength of the scientific study. Essentially students will be asked to interrogate the data and methodology used and to reflect on the level of scrutiny that the data received from the scientific community. When evaluating scientific claims, students may not have sufficient understanding of the science being used as "evidence" to argue for or against a claim.For example, claims supported by evidence from a small sample size or a targeted demographic are statistically insignificant and scientifically unreasonable if applied to a more diverse population, respectively. Claims that cannot be tested or repeated by others also violate the principles of science. Teachers may wish to co-construct a checklist of criteria with students to help guide their thinking.

Table 7. Determining if a claim is scientifically valid

Is the Claim Scientifically Valid?	
• Can the experiment be reproduced?	• Were the limitations of the findings stated?
• Was it tested? How valid is the evidence (data)?	• Does the claim fit in with well-established science?
• Were controls for bias used?	• What are the possible alternative explanations?
• How well were confounding variables controlled?	• Is the claim embraced by the scientific community?

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

Nature of Science

NoS 2	*Learners are expected to ...*					
	analyze factors that influence decisions to accept scientifically unreasonable claims.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
				■		

Achievement Indicators

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

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

b examine how factors (e.g., causal illusion, confirmation bias, correlation, risk perception, social media, lack of trust) can influence an individuals' decision regarding, for example, vaccinations, life style, food choices, alternative medical treatments;

c analyze societal trends related to the acceptance of explanations that are supported by poor science;

d identify and describe possible consequences that may result from decisions based on misinformation; and

e recognize that flexible and open-mind sets are required to change an opinion when new high-quality evidence becomes available.

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

ELABORATIONS

NoS 1 focuses on how to distinguish scientifically supported claims from those that are not scientifically reasonable. The purpose of NoS 2 is to develop an awareness of factors that influence us to believe the latter. Some of these factors include a lack of understanding, correlation versus causation, various cognitive biases, and a belief system of some individuals that they are without bias. Explicitly teaching students how to recognize the presence of these influences can lead to making better informed decisions. Causal illusion is a cognitive bias or belief that two unrelated events are indeed related (Matute 2015). Humans are naturally predisposed to causal illusions and it has been suggested that such biases are evolutionary advantageous by helping us avoid things that are dangerous (Caulfield 2017). However, racial and cultural biases, financial hardships, public health issues, and the increase in belief in pseudosciences have been attributed to causal illusion and a lack of scientific thinking. A classic case of causal illusion is the incorrect link between vaccines and autism. The effect of causal illusion is magnified by the presence of confirmation bias and the influence of popular culture (Caulfield 2017). Individuals tend to look for evidence to confirm what they have decided to believe. Furthermore, in today’s social-media dependent world, popular culture and celebrities greatly influence the way we think and what we believe, especially when it comes to health issues (e.g., diet trends, vaccines, GMO’s, exercise). At the same time some of these influences create a distrust of scientists and scientific knowledge. NoS 2 addresses a critical aspect in the development of scientific literacy. Students should be explicitly taught the difference between correlation and causation ("What do scientists do?" p.20) and be able to identify examples of both. They should be encouraged to reflect on their own experiences with casual illusion and identify examples of confirmation bias in their everyday conversations. Linking casual illusions to optical illusions can help students realize the ease with which our mind can be fooled. Students should appreciate that scientists also are subject to these biases and that science protocols strive to reduce bias to ensure accurate identification of causal relationships. The occurrence of causal relationships is not an opinion. They either exist or they do not. The scientific process includes peer review and constant revision and refinement of scientific knowledge. Over time, this review and revision process acts as a “filter” removing invalid information and leaving a more accurate understanding of a causal relationship. This process is demonstrated by the story of how smoking was identified as a cause of lung cancer ("What do scientists do?" p.20). The development of the germ theory (CK 1.2) is an excellent example comparing the development of knowledge using scientific thinking versus causal illusion

PROCEDURAL KNOWLEDGE

PK 1	*Learners are expected to ...*					
	synthesize information from reliable sources to extend understanding of scientific concepts.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
						■

Achievement Indicators

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

a explain the purpose for their reading;

b select reliable sources of scientific information;

c discriminate between relevant and irrelevant information;

d interpret information presented in text features, not limited to, but including tables, graphs, charts, and diagrams;

e answer questions regarding text that are literal, inferential, and evaluative in nature; and

f integrate information from multiple reliable sources (print and electronic) to extend their knowledge about scientific phenomena.

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

ELABORATIONS

> *"When we write, we compose thoughts on paper. When we read, we compose meaning in our minds." (Harvey 2007)*

Specific curriculum outcome PK 1 is to be integrated throughout the Science 421A curriculum. For instance, this outcome is addressed when working with outcomes such as NoS 2, DP 1 (argument), and DP 2 (career). When assigning questions that accompany a reading, the purpose of the questions and the cognitive demand being placed on the reader should be considered. Literal questions, which require students to recall or extract specific information from the text, are considered to be Level 1 questions. While these are considered to be lower level, they are necessary when students are developing an understanding of a new topic. Assessment of reading comprehension at this level usually involves totaling the number of correct responses. Inferential questions (Level 2) require students to connect ideas in order to interpret information that is implied but not explicitly stated. Evaluative questions are Level 3 in nature. These questions place the highest cognitive demand on students by requiring them to make a judgment about the content or synthesize information with other knowledge or experiences. Evaluative questions would naturally accompany readings within the context of topics addressed by NoS 2 and DP 2. Students are expected to respond to questions from all three levels, and it is recommended that teachers use exemplars and model how to interact with the text when answering questions that are inferential or evaluative in nature.

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

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

Table 8. Literal, Inferential, and Evaluative Questions

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

Procedural Knowledge

PK 2	*Learners are expected to ...*					
	compose written arguments which effectively communicate scientific reasoning.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
					■	

Achievement Indicators

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

a explain the importance of argumentation in scientific inquiry;

b state the claim (which may in the form of a hypothesis);

c state their position regarding the claim;

d discuss evidence that supports the claim;

e discuss limitations of the evidence provided (i.e., scientific errors when argument is based on an experimental evidence);

f demonstrate effective scientific writing style (i.e., word choice: technical, objective, non-ambiguous, non-emotive);

g demonstrate proficiency using informational text features and technical writing conventions by

- *creating purposeful, tables, graphs, models and diagrams (e.g., concept diagrams, flow-charts, biological, technical sketches) that clearly communicate the nature of relationships within data, devices, apparatuses, or scientific concepts (e.g., effect of force, energy transfer, cell structure),*
- *apply International Union of Pure and Applied Chemistry (IUPAC) conventions when naming elements and binary molecular and ionic compounds*
- *representing chemical reactions and the conservation of mass using balanced symbolic equations,*
- *using International System of Units (SI) conventions for units of measurement (e.g., Newtons (N), mass (kg), energy (J), length (m);*

h understand and avoid plagiarism; and

i 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

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

Scientific argumentation is "a critical-thinking skill that helps students propose, support, critique, refine, justify, and defend their positions about issues. . . . [It] is a natural element of scientific inquiry" (Llewellyn 2013). Logical reasoning is implied in argumentation, which is fundamental to the process of science. Written arguments can be in the form of lab reports, which are a natural continuation of the inquiry process. They can also be based on an issue or development in science or technology that is being examined while students are working towards DP 1 and NoS 1. Not all science-based reports are argumentative in nature. This is true for some lab investigations that are not hypothesis-driven and research reports that review a topic such as a specific infectious disease.

When communicating new findings in science, the writer makes a claim that a hypothesis is to be accepted or rejected. The author builds this argument using logical reasoning to support their position with evidence collected during the investigation. Analyzed data (not raw data) is scientific evidence. The discussion section of a report presents the argument. Publishing a scientific paper enables a scientist to have their research and scientific reasoning reviewed, replicated, challenged, and validated by other members of the scientific community. This peer review process is the rebuttal portion of the scientific argument.

The organization and style of scientific writing emphasizes clarity, objectivity, and the use of specialized technical language to ensure that the message communicated is clear and unambiguous. Implied in "effectively communicate" in PK 2 is the quality or clarity of writing based on criteria such as word choice, organization, fluency, and mechanics. To develop proficiency with technical writing, students can be provided with opportunities to practice skills specific to individual sections of lab reports (e.g., writing a sequential procedure, recording observations, interpreting patterns and trends in graphed data, and formulating a discussion) before completing a whole report. The use of exemplars and gradual release of responsibility for learning ("Instructional Strategies" p.34) are recommended as instructional strategies. Teachers should explicitly teach students how to avoid plagiarizing the work of others.

In addition to technical reports, students should be provided with writing tasks for the purpose of learning science (e.g., a narrative describing two substances colliding and reacting, a narrative describing the path of an object subject to a variety of forces, a translation of a chemical reaction, a reflection in a science journal regarding something they learned, a written conversation regarding an issue in science (DP 2), or a mind map depicting what they learned about cell theory). These writing activities help students process and internalize the scientific concepts being examined. Teachers should consider the intended purpose of writing before deciding to assess formatively or summatively.

Procedural Knowledge

PK 3	*Learners are expected to ...*					
	design and evaluate a scientific investigation which examines a cause and effect relationship.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
					■	■

Achievement Indicators

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

a use the following vocabulary appropriately: confounding variable, control, dependent variable, hypothesis, independent variable, prediction, reliability, repeatability, reproducibility, test, variable;

b deduce the question being asked and/or hypothesis being tested in an investigation;

c identify the independent variable (cause), dependent (effect/responding), and controlled variables of an investigation;

d distinguish between scientific errors and mistakes (i.e., blunders);

e evaluate how well variables were identified and controlled;

f identify possible sources of bias;

g suggest, with reasoning, if the use of a control would have strengthened the experiment;

h identify weaknesses in the methodology used (e.g., cannot be repeated, does not allow for the collection of data that can be used to answer the original question);

i record and discuss the precision and accuracy of measurements; and

j evaluate if the conclusion is reasonable in consideration of the study design and data collected.

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

ELABORATIONS

During intermediate grades students were introduced to experimental design and practiced generating descriptive and causal questions, identifying variables, writing and testing hypothesis, and identifying scientific errors (specifically, bias and lack of control of variables). In addition to designing an investigation, students in Science 421A are expected to analyze and evaluate the design of experiments more deeply. Sources of experiments to evaluate include videos of experiments, cases studies, or experiments designed by students or their peers. Criteria used to evaluate science investigations include reproducibility, repeatability, reliability, accuracy, and precision.

Independent variable: the variable that causes a change in another variable. This is the only variable to be manipulated by the experimenter.
Dependent variable: the responding variable that is affected by the independent variable. The experimenter observes or measures any changes that occur.
Variables to be controlled: to be certain that the independent variable is causing the observed effect on the dependent variable, all other variables must be controlled or kept constant. Variables that are not properly controlled can inadvertently affect the results and are sometimes called confounding variables.
Hypothesis: tentative, testable explanations that answer causal questions. It is a misconception that hypotheses are "guesses." (A prediction statement describes what is expected to happen during the test if the hypothesis is correct; the prediction statement includes the direction of change (e.g., increase or decrease).

Table 9. Independent and Dependant Variables

Causal Question (What affects? What causes?)	**Possible Causes**	**Variable Selected as Independent Variable**	**Dependent Variable**
What affects the volume of CO_2 gas produced in a yeast solution?	temperature, amount of yeast, time, amount of sugar, amount of water in yeast solution	quantity of sugar	volume of CO_2 gas produced
Hypothesis	**How hypothesis will be tested**	**Prediction**	**Variables to control**
The quantity of sugar affects the volume of CO_2 gas produced by a yeast mixture	I will vary the grams of sugar put in the yeast solution	If I increase the mass of sugar, the volume CO_2 gas will increase	temperature, amount of yeast, time, amount of water in yeast solution

A fundamental principle of science is that results produced by an investigation are repeatable and reproducible.
Repeatable means that an individual using the same equipment or apparatus obtains consistent (reliable) results or measurements.
Reproducible refers to whether or not the experiment performed elsewhere by another investigator will yield the same results.

Qualitative observations rely upon using the senses to record descriptive observations. Qualitative observations are subjective and therefore can be influenced by limitations of our senses, our perceptions, and bias.
Quantitative observations are based on quantities or measurements and considered to be more reliable. Much of the effort put into designing scientific investigations is to ensure that the obtained results are accurate and reproducible. Precision, a measure of the degree of reliability, is also considered in science and reported with the results. A hands-on activity will help students develop conceptual understanding of precision of measurements.

The intent of PK 3 "i" is that students can properly record and report measurements using both analog scales (digits read plus one that is guessed) and digital scale (measurement +/- uncertainty value). It is not the intent of SCI421A to carry the error through a series of calculations (significant figures in measurement to be considered in the context of precision, not in calculation).

ELABORATIONS

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

Table 10. Sources of Error

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

Procedural Knowledge

PK 4	*Learners are expected to ...*					
	create a machine that utilizes several transfers of energy to perform a simple task using an engineering design process.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
						■

Achievement Indicators

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

a identify the problem or challenge;

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

c collaboratively decide upon success criteria for a solution to a problem and select one solution that best meets the criteria with consideration of limitations;

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

e design and construct a prototype that utilizes several transfers of energy to perform a simple task (e.g., Rube Goldberg device);

f test and evaluate the effectiveness of the machine to perform a task according to criteria,

g analyze qualitatively and quantitatively energy transformations within the system; (links to CK 3.2) and

h reflect upon the successes and difficulties experienced during the design process, both technical and those related to personal understanding and skill. (links to DP 2)

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

ELABORATIONS

The purpose of PK 4 is to engage students in the practice of engineering design while experientially learning concepts such forces, potential energy, kinetic energy, and conservation of energy. Design engineering is a form of STEAM problem-solving ("STEAM Problem-Solving Processes" p.30) and requires both analytical and creative thinking. PK 4 should be integrated with CK 3.1 (forces), CK 3.2 (energy transfer), and DP 2 (career-related skills).

An example project that could be used to meet this outcome is a Rube Goldberg machine. These devices, named after their creator, are composed of a series of simple machines that are connected in a manner to create a domino cause and effect. One component of the system performs a simple task that triggers another component and so on, until a final task is accomplished. Energy is converted or transferred between each component and students must problem-solve to ensure that sufficient energy is initially put into the system to allow the final task to be performed.

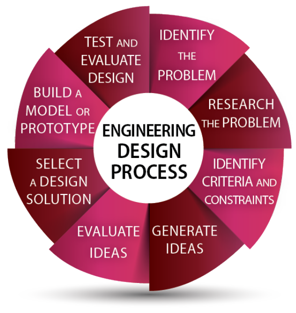


Figure 14. Engineering Design Process

Teachers may wish to begin a project of this nature by introducing the concept of engineering design and have students complete a reverse engineering activity that examines the mechanics and design of an object such as a flashlight, a pulley, or a wind-up toy. Students should understand that while trial and error are part of design, engineers use a systematic process which includes phases such as defining the problem, identifying constraints and criteria, researching the problem and brainstorming (see figure below). Research may not only involve searching online for previous designs and solutions, but also performing labs that help develop understanding of scientific concepts such as forces, acceleration, velocity, kinetic energy, and potential energy that are required to design devices of this nature.

When generating ideas for their design, students should consider constraints (e.g., limitations of materials and size) and the criteria for success (i.e., accomplishment of the final task). To design a solution, students must make decisions regarding the number of components in the device, the order of the components, which items will be used to create paths and transfer energy, and what measures will be taken to ensure that there is sufficient energy input into the system at the start. They should be able to communicate their prototype using sketches, which indicate points of energy transfer or loss.

The analysis at this level does not have to be overly complicated but should include identification of the types of energy transfers employed and energy calculations using the following equations.

Potential energy of the top = potential energy + kinetic energy at the midpoint
Potential energy at the top = kinetic energy at the bottom
$(mgh)_{top} = (mgh + \frac{1}{2}mv^2)_{middle} = (\frac{1}{2}mv^2)_{bottom}$

$E_t = Ek + Ep$ where E_t is total energy,
E_k is kinetic energy in joules (J) = $\frac{1}{2}mv^2$
E_p is potential energy in joules (J) = mgh

m is mass in grams, h is height in meters,
v is velocity (m/s), and g is gravitational acceleration (9.81 m/s^2)
Teachers may wish to have students co-construct success criteria for assessment. Assessment can include observations of collaborative skills (DP 3), students' reflections of the process, students' evaluations of their design, a simple analysis of energy transfer, and technical drawings.

PROCEDURAL KNOWLEDGE

PK 5	*Learners are expected to ...*					
	perform investigations that examine the microscopic structure of cells, chemical reactivity, and the relationship between energy, forces, and matter.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating

Achievement Indicators

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

a use the following vocabulary appropriately: accuracy, calibrate, data, infer, precision, qualitative observation, quantitative measurement, results, unit;

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

c explain the advantage of quantitative measurement over qualitative observations;

d apply safe practices when using techniques, equipment, and chemicals including

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

e select and use equipment and materials appropriately for the investigation;

f record measurements that reflect the precision of the measuring device;

g record qualitative and quantitative observations in a systematic and organized manner (e.g., considers before, during, and after observations; does not infer; uses a table or bullets; records date, title, or other identifiers for data; draws labeled sketches);

h draw a biological diagram to record what has been observed through the microscope (provide magnification, use proper labeling techniques, stippling); and

i problem-solve as necessary during the investigation to ensure the collection of appropriate data (e.g., adjust microscope settings, stabilize an apparatus, calibrate a thermometer, or tare a balance).

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

ELABORATIONS

Specific curriculum outcome PK 5 reflects the second stage of the scientific inquiry process, performing and recording (Table 4 p.23). Well-designed, hands-on lab investigations provide the learner with engaging opportunities to develop proficiency with manipulative skills (i.e., those involved with the handling of equipment and materials) while encouraging critical thinking and problem-solving skills. Classroom-laboratory experiences also facilitate student understanding of abstract scientific concepts such as chemical reactions, gravity, and forces.

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

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

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

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

Table 11. Suggested Labs within the Context of Science 421A

Topic	Description
Cells and Infectious Disease	preparation of a cheek cell smear microscopic examination of onion root tip or prepared slides simulation lab of disease transmission (e.g., Glo-germ labTM) computer simulation to explore epidemics and impact on societies (e.g., Plague Inc.)
Real World Chemical Reactions	activity examining types of chemical reactions examination of factors affecting reaction time of Alka-Seltzer & water examination of conservation of mass
Designing Mechanical Systems	reverse engineering lab (deconstruct a flashlight, an old watch, or wide up toy examination of relationships between mass, height, and force simulation (e.g., PhET.com) investigating velocity, acceleration, energy (roller coaster)

Procedural Knowledge

PK 6	*Learners are expected to ...*					
	analyze data to determine patterns, trends, and causal relationships.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating

Achievement Indicators

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

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

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

c classify objects and systems according to similar characteristics (e.g., bacteria and viruses, contact and non-contact forces, types of chemical reactions); and

d describe and interpret patterns and trends in graphed data (e.g., impact of disease on populations, linear relationships between mass, force, and acceleration.

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

ELABORATIONS

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

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

To meet this outcome students must demonstrate that they know how to analyze data. Numeracy skills, essential for scientific analysis, should be reinforced (e.g., measuring, graphing, calculating, problem-solving) where appropriate. Data refers to both primary (i.e., collected by the student) and secondary (provided by the teacher or from online sources). In Grade 9 Science, graphical analysis and classification were identified as main areas of focus for this outcome. Examples of opportunities to think analytically in SCI421A include, but are not limited to

- examining patterns in the spread of disease;
- comparing and contrasting bacteria and viruses;
- determining patterns in chemical reactions; and
- analyzing energy changes in a mechanical system.

Content Knowledge

CK 1.1	*Learners are expected to ...*					
	explain why the cell is considered a living system which is responsible for the continuity and diversity of life.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating

Achievement Indicators

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

a use vocabulary including, but not limited to: bacteria, cell membrane, cell theory, eukaryotes, multicellular, organelles, prokaryotes, spontaneous generation, system, unicellular, viruses;

b distinguish between living and non-living things;

c locate cell boundaries and visible organelles using a microscope (links to PK 5);

d describe how the cell is both a system and a component of a system;

e compare and contrast characteristics that are used to classify eukaryotic and prokaryotic cells;

f provide reasons why viruses are considered non-living;

g recognize that the nucleus of the cell contains genetic information that is passed on from cell to cell; and

h identify different types of cells microscopically (animal, plant, bacteria cells).

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

ELABORATIONS

Biologists examine the structure, function, growth, reproduction, evolution and interactions of living things; biology is the study of life. During grade eight science, students studied the structure and function of plant and animal cells as well as the interdependence of cells, tissues, and organs. These concepts will be expanded upon in Science 421A as students examine the relationship between cells, continuity of life, and evolution using the context of viruses, bacteria ,and antibiotic resistance.

Cell theory explains our understanding of the cell as the basic unit of life. Like all theories, it is complex and supported by many lines of evidence from different fields of science. Students should examine evidence that supports the following principles of this theory.

1. The development of the cell theory began with the discovery that all living things were composed of cells; cells are to living things what atoms are to chemicals. Having students use a microscope to try and "discover" cells and their boundaries prior to explicitly telling them what to look for, will simulate the experience of scientists prior to the discovery of cells.

2. A system is an interdisciplinary concept that describes a group of individual parts, components, that interact as a whole to accomplish a task. Systems are the focus of scientists within biology, chemistry, and physics. Cells can be considered as both components of systems and systems unto themselves. Within their boundaries are organelles that enable life's processes: respiration and energy flow, production and packaging of specialized substances, storage of the blueprint (DNA) to pass on its characteristics to the next generation of cells. At this level, students should explore how the cell functions as a system using simulations and models rather than memorizing names of organelles.

CK1.1

3. All cells come from preexisting cells and hereditary information is passed from cell to cell (generation to generation) during cell division. Small changes called mutations occur in genetic material each time a cell divides. These mutations are what have caused all the variation and diversity of living things on the Earth over time. Some of these mutations help an organism to adapt better to its environment (e.g., resistance to an antibiotic). This in turn ensures that the cell will survive and pass on the adaptation on to future generations of cells.

Even when scientists first recognized that these small units were the basic building blocks of all living things, they thought that cells spontaneously appeared. When Louis Pasteur demonstrated that life comes from life, or that all cells come from other cells that grow and divide, it resulted in not only modification of the cell theory but a paradigm shift in thinking. Students are not expected to memorize phases of cell division in Science 421A, but develop a basic understanding that hereditary information (DNA) is passed on from cell to cell during cell division. They should examine cell microscopically to find evidence of cell division and consider bacterial colonies as evidence of growth from a single cell. Students should also reflect upon criteria used to define life and relate the inability of viruses to independently reproduce genetic material to the rationale used to classify them as non-living.

4. Energy flow is necessary for life and occurs through the process of cell respiration (and photosynthesis) which are chemical reactions (CK 2.2). The carbohydrates we eat are ultimately broken down into glucose which is a reactant in cellular respiration. During the reaction, energy is released that can be used by the cell. Cell death occurs when energy is unavailable to a cell. When too many cells die in an organ of a complex organism, the organ will no longer function and the organism dies. Students should be able to explain how life depends on cellular respiration.

5. While all cells have the same basic chemical composition, they can differ significantly in form and function. These differences are used to classify cells and organisms. These difference are also exploited to develop treatments for bacterial infections. Students should be familiar with basic difference in the structure of viruses and bacteria at a very introductory level.

CONTENT KNOWLEDGE

CK 1.2	*Learners are expected to ...*
	understand the transmission and prevention of infectious disease and analyse its impact on society.

Remembering	Understanding	Applying	Analysing	Evaluating	Creating

Achievement Indicators

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

a use the following vocabulary appropriately: antibiotic, antibody, mutation, epidemiology, germ theory, herd immunity, immune system, infection, infectious disease, pathogen, transmission, vaccine;

b provide examples of diseases caused by bacteria versus viruses;

c explain how technology and the development of the germ theory influenced our understanding of infectious disease (link DP 1);

d compare and contrast the use of antibiotics and vaccines;

e describe modes of transmission of infectious disease (i.e., direct: person to person, droplet and indirect: air-borne, contaminated objects, food and drinking water, animal to person, vector-borne, environmental reservoirs);

f identify ways to prevent the spread of infectious disease (i.e., condoms, handwashing, vaccines, mosquito nets, water sanitation) based on mode of transmission;

g relate the concept of herd immunity to disease outbreaks (i.e., vaccine development, link to DP 1);

h investigate patterns in transmission of infectious disease (using case studies, simulations) and deduce patient zero (link to PK 2 and PK 6);

i distinguish between pandemics (global), epidemics (restricted to a region), and endemics (sustained number in a population); and

j examine the social/economic impact of pandemics/epidemics (e.g., HPV, measles, whooping cough, hepatitis, HIV [AIDs], smallpox, bubonic [black] plague, influenza, Zika virus) on human populations and/or epizootics on animal and human populations (e.g., bat white-nose syndrome, sylvatic plague/bubonic plague, mange/scabies).

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

ELABORATIONS

The purpose of CK 1.2 is to encourage students to connect their understanding of the cell to the microbial world of pathogens and develop a more in depth understanding of science behind infectious disease and its transmission. Infectious disease impacts every human in some way during their life, yet most people do not consider the role they play its spread or the complexity of the science behind it. In achieving this outcome should realize that the prevention of disease is evidence-based and that simple changes in behavior may help prevent transmission of something that in not visible to the naked eye. CK 1.2 should be integrated with NoS 1, CK 1, and DP 2.

One of the driving forces behind the development of the cell theory (CK 1.1) was the desire to understand infectious disease and specifically, those that resulted in high death tolls. Since most pathogens are minute, technologies that allow us to detect and examine them have been essential in the development of this scientific knowledge (DP 1). Today, science continuously pursues the understanding of ever-evolving pathogens by examining aspects such as morphology, biochemistry, genetics, reproduction, modes of transmission, and their interactions with hosts. The applied health sciences such as medicine, microbiology, immunology, pharmacology, and epidemiology continuously look for new scientific understanding of pathogens to develop strategies in an effort to reduce the impact of infectious disease at both the individual and population level. A brief look at the history of a disease such as plague and the development of the germ theory can be used as a hook to engage students. It also provides opportunities for students to analyze data related to the impact of epidemics on populations, and of the development of new medical developments such as vaccines on rates of incidence of disease. Such data analysis supports PK 6.

There are several types of infectious agents (smallest to largest: prions, viruses, bacteria, fungi, protozoan parasites). For the purpose of Science 421A mostly viruses and bacteria will be considered. Generally RNA viruses (e.g., influenza virus, HIV, poliovirus, measles virus) mutate at a higher rate than DNA (e.g., smallpox, herpes). This characteristic increases their likelihood of causing an epidemic. The rate of mutation also impacts the success of an immunization program. For example, some years the influenza virus mutates in an unpredictable way resulting in a less effective vaccine.

The primary purpose of vaccines is prevention. Vaccines stimulate a protective immune response in organisms without causing the illness. When a vaccine is administered, the host's immune system produces antibodies which recognize chemicals (e.g., proteins) associated with the pathogen. Vaccines are the main line of defense against viral diseases; they are used to prevent some non-viral diseases such as whooping cough (Bordetella pertussis) which is a bacteria infection. Vaccines are not used to treat disease.

Herd immunity is a foundational concept to understanding the prevention of infectious disease. In any population there are a number of individuals who cannot be vaccinated and remain susceptible to infection (e.g., babies too young to be vaccinated, immune-compromised individuals). Herd immunity is an indirect effect whereby these individuals are protected if a certain proportion of individuals in their community are immune (i.e., through vaccination or previous infections). In regions where a disease is "eliminated" vaccination is the only way to achieve immunity. With globalization, these diseases can re-emerge in regions when travelers carry infection to communities that do not have herd immunity due to inadequate vaccination rates. This is a major concern for population health. Students can analyze data and graphs of increases in infection rates of diseases (such as measles and whooping cough) in areas where vaccination rates have declined. They should also complete a laboratory activity (PK 5) that allows them to investigate transmission.

Content Knowledge

CK 2.1	*Learners are expected to ...*					
	predict the products of chemical reactions.					
	Remembering	Understanding	Applying	Analysing (highlighted)	Evaluating	Creating

Achievement Indicators

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

a use the following vocabulary appropriately: balanced reaction, chemical equation, chemical formula, chemical/physical property, chemical/physical change, coefficient, product, reactant, subscript, yield sign;

b identify the reactants and products in a chemical equation;

c apply International Union of Pure and Applied Chemistry (IUPAC) conventions when writing the formula and naming binary molecular and ionic compounds, which include:;

- binary ionic compounds that contain multivalent transition metals (e.g., Fe(II), Fe(III), Cu(II), Cu(I));
- binary ionic compounds that contain common polyatomic ions (e.g., OH^-, NH^{4+}, NO^{3-}, HCO^{3-}, CO^{3-}, SO_4^{2-}, PO_4^{3-}); and
- binary molecular compounds using Greek prefixes (mono to hepta);

d associate the occurrence of a new colour, a gas (bubbles or odor), or a solid (precipitate) during a chemical reaction with the presence of a new substance;

e identify observable energy changes that suggest a chemical reaction may have occurred (i.e., increase or decrease in temperature, the production or light or sound, explosion, shockwave);

f illustrate with a model or diagram that atoms retain their identity during chemical change and that the number of each type of atom present after a reaction is conserved;

g understand that reactant atoms are rearranged to form new substances (products) in predictable ways;

h analyze simple patterns in chemical reactivity (single/double displacement, decomposition, synthesis, combustion);

i apply the law of conservation of mass to write balanced chemical equations; and

j deduce formulas of products for simple chemical reactions.

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

ELABORATIONS

During Grade 9 Science, students examined patterns in atomic structure, compounds, chemical and physical properties, and the periodic table. They represented atomic structure using models such as Bohr and Lewis diagrams (NoS). With the support of manipulatives, students were introduced to writing formulas for ionic and molecular compounds. Emphasis was placed upon the determining the ratio of elements in compounds formed by the first twenty elements. Nomenclature was briefly introduced. In SCI421A students will be expected to develop sufficient fluency when naming and writing formulas to enable them to write chemical equations.

Chemical equations are the language of chemists. Students who meet CK 2.1 should be able to write and deconstruct symbolic chemical equations and identify which substances are the reactants and which are the products. They should recognize that chemical reactions can be classified or grouped according the patterns in which reactant atoms combine to form products. This is a link to the nature of science—science presumes that the world is orderly and behaves in predictable ways. Students should be cognizant of the facts that combustion, synthesis, decomposition, double-displacement, and single-displacement are not the only classifications of chemical reactions.

Implicit in this outcome is the application of rules and conventions for nomenclature (naming chemicals). During grade nine, students were introduced to writing formulas and names of binary ionic compounds formed using the first 20 elements and simple, common molecular compounds such as O_2, CO_2, H_2O. When planning instruction, teachers should consider that the intended purpose of teaching the naming and writing of formulas in Science 421A is not to become fluent in naming and writing formulas, but to provide students with ample skill to deduce products of chemical reactions. Students who continue on to study chemistry will become more proficient in nomenclature.

To meet PK 2.1, students are expected to write balanced symbolic chemical equations and demonstrate conceptual understanding of the law of conservation of mass. This law is important in determining the quantity of product. It is also important in the consideration of renewable and non-renewable resources; there is a finite amount of matter on the Earth resulting from combinations of only 92 types of natural elements. Elements can be locked into substances (e.g., plastics) that do not readily decompose (DP 1). To reinforce this concept, teachers may have students use the Royal Society of Chemistry's online periodic table to examine supply risks for elements (http://www.rsc.org/periodic-table/).

Students frequently have the misconception that reactants change their appearance during a chemical reaction. This is evident when students do not make the connection between the evidence of a chemical reaction (e.g., colour, heat, bubbles) and the new product. This misconception may be reinforced by the phrase "chemical change". Learning to associate bubbles, precipitates, and colour changes with new products not only deepens conceptual understanding of chemical reactivity but also reinforces the concept of conservation of mass. Students should be expected to use reasoning to link evidence to the claim that a chemical reaction has occurred during lab investigations.

Table 12. Observations and Explanations

Observation	Explanation why observation indicates a chemical reaction
Colour change	If the new substance formed is a different colour from the original reactants, a colour change is observed. The new colour IS the new substance; the original substance is not actually changing colour, it is no longer present in quantities that can be observed.
Formation of a precipitate	When a solid comes out of solution during a chemical reaction, it is called a precipitate. The precipitate is a new substance that is not very soluble.
Formation of bubbles	Bubbles indicate a gas is formed. If testing indicates that the new gas is a new substance a chemical reaction has occurred. If the gas formed is the same substance as the original, such as water vapour resulting from boiling water, it is not a chemical reaction.
New odor	An odor indicates that a new substance has formed as a gas.
Sound	Whenever a chemical reaction occurs, energy is used to break the attractions (i.e., bonds) between atoms and released when these same atoms form other bonds. We observe the difference between energy used and energy produced as heat, light and/or sound. At this level students only need to understand that particles are being rearranged, which involves energy.
Light	
Temperature change	

Content Knowledge

CK 2.2	*Learners are expected to ...*					
	analyze real world chemical reactions by applying principles of chemical reactivity.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
				■		

Achievement Indicators

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

a recognize that chemical reactions are the only means by which new substances are formed in real life;

b identify the products and reactants of a novel chemical reaction using written descriptions or chemical equations (that include chemical formulas or structural diagrams);

c describe changes in the rearrangement of atoms that occurred during a chemical reaction when provided with symbolic or pictorial representations (i.e. Bohr, Lewis Dot); and

d deconstruct and analyze a novel chemical reaction when provided with any combination of descriptions, diagrams, or chemical word/skeleton/balanced equations.

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

ELABORATIONS

Chemical reactions are occurring constantly within us and around us and are intrinsically woven into our lives. Our life depends on photosynthesis and cellular respiration. In our cells, trillions of reactions are occurring each second. When we breathe out carbon dioxide and sweat water, we are releasing products of a chemical reaction. We use oxidation reactions to our advantage in batteries, but they cost us billions of dollars every year as our structures and machines rust, and our food spoils. Understanding the patterns of reactivity has enabled scientists to create new substances, which is evident in the fact that in 2015 a patent for the 100 millionth chemical substance was registered in the Chemical Abstracts Service (CAS) registry—the world's largest database of unique chemical substances.

CK 2.1 familiarizes students with the concepts of chemical reactions/equations, reactants versus products, and conservation of matter. Students often do not transfer this understanding to what is happening in the real world. Learning to classify reactions as four or five types can lead to a narrow view of chemical reactivity. The purpose of CK 2.2 is to broaden students' awareness of the prevalence of chemical reactions in their lives and apply their understanding of chemical reactions to real world examples.

Students should research examples of chemical reactions beyond what is taught as part of CK 2.1. A project of this nature can also be used to meet SCO PK 1. Higher level thinking is required when students are asked to extract and synthesize information from their reading. A good place to begin is to have students consider words in our everyday language that represent chemical reactions: burn, neutralize, rot, ferment, rust, oxidize, bleach, decompose, and sprout. Provide students with one or two terms and have them work in groups to generate others. Following this they could research a chemical reaction related to something familiar such as cleaning, pollution, plastics, clothing, cooking, agriculture, hair treatment, batteries, or food preservation. Having the students present their findings to the class will allow them to see many examples of chemical reactions and begin to comprehend the extent to which chemical reactions occur.

Examples of Chemical Reactions

- polymerization (polyethylene/plastics)
- Maillard reaction (browning of meat)
- digestion (bread or meat)
- biological formation calcium carbonate (shells)
- Haber-Bosch Process (production of ammonia for fertilizers)
- anaerobic respiration (in algal blooms and food spoilage)
- hormone synthesis (the Pill)
- acid-base reactions (acid rain, hair treatment)
- oxidation in food spoilage (browning of apples)
- electrolysis of water (fuel cells)

Students are expected to analyze a reaction by identifying reactants, products, and the types of elements present. They should include other qualitative descriptions such as if it is a slow reaction, is explosive, gives off heat, or requires energy to initiate. DP 1 connections can be made by asking students to evaluate the importance of the chemical reaction and rank its importance compared to those researched by their peers.

Content Knowledge

CK 3.1	*Learners are expected to ...*					
	apply the relationship between mass, force, and acceleration of objects.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
			■			

Achievement Indicators

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

a use the following vocabulary appropriately: acceleration, force, friction, gravity, inertia, mass, weight;

b provide examples of contact and non-contact forces;

c describe qualitatively the relationship between mass and weight;

d compare and contrast the inertia of objects of different masses and the forces required to change their motion (i.e., application of Newton's first law);

e explain that gravity is a force of attraction between all objects and does not have to be associated with Earth;

f calculate the net force acting on a object and describe the resulting impact on its' motion using pictorial representations;

g describe the responding action that occurs as a result of a force being placed on an object (i.e., apply Newton's third law to analyze contextualized scenarios);

h investigate the effect gravity, friction, and applied forces on the acceleration of objects of equal mass and those of difference masses;

i apply Newton's second law, F = m x a (force = mass x acceleration) to solve contextualized problems qualitatively and quantitatively; and

j identify units associated with force, mass, and acceleration.

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

ELABORATIONS

Newton's first two laws will be used to predict the motion of an object at the macroscopic level.
Newton's first law: Objects remain at rest unless an unbalanced force (push or pull) causes them to move. Once in motion the object continues in the same direction and speed (constant velocity) unless an unbalanced force causes a change in motion (acceleration).

Newton's second law: describes the relationship between force, mass, and acceleration of an object with the equation: Force on object = mass of object x acceleration of object (F = m x a). Considering an object with mass m"

- a small force on a mass results in small acceleration (↓F = m x a↓)
- a large force on the same mass results in larger acceleration (↑F = m x a↑)

A small force on a small mass AND a large force on a large mass can result in the same acceleration.

Certain vocabulary is required to work with Newton's laws. See Appendix D for examples of instructional strategies for teaching vocabulary.

- *Force (F):* can be considered a push or a pull; forces have magnitude and direction. Our senses can detect forces (e.g., during a shove, elevator ride, or plane lift-off). Newton's laws are concerned with net forces or the sum of all the forces acting on an object on a specific axis. Forces on a specific axis are analyzed and the difference between these forces is the net force.
- Forces are either contact forces (e.g., collision, friction, tension [applied and spring]), or non-contact forces (i.e., weak and strong nuclear forces, electrostatic and magnetic forces, and gravitational forces).
- *Friction (F_f):* a contact force that objects exert on each other when they rub together; friction is the force that opposes motion and stops objects from perpetually moving.
- *Gravity (g)*: a non-contact force that is the pull that two objects have on each other; it is the weakest of all non-contact forces.
- *Inertia:* the tendency for an object to keep moving or resist moving; how hard it is to move an object.
- *Mass (m):* a measure of how much of there is of something and its inertia; objects with little mass have small inertia; objects with a large mass have large inertia.
- *Weight (Fg)*: the force gravity exerts on an object; how hard another object is pulling on an object is its weight. Weight is not that same as mass. Weight is calculated by multiplying the mass by the acceleration do to gravity (Fg = mg).
- *Acceleration (a):* a change in speed OR direction; speeding up AND slowing down are considered acceleration; changing direction but maintaining speed is also acceleration.

There are many misconceptions regarding Newton's laws (especially relating to gravity) even though we experience these laws in action every day. Though exploration and hands on activities students should develop an understanding that:

- as an object falls to ground, it picks up speed (i.e., it is accelerating), therefore a net force must be acting on it. The force apparently pulling the object to the surface is gravitational force (Weight);
- gravity exerts a greater pull (force) on objects with a greater mass (you can feel this difference in pull when you hold objects of different masses in each hand); this is supported by Newton's second law, F = ma;
- gravity is not only exhibited by the Earth; it occurs between any two masses (even the student and their cell phone!);
- All objects in free-fall on Earth have the same gravitational acceleration (g) which is 9.81 $m \cdot s^{-2}$ (this presumes no air friction, which is usually present);
- the mass does not affect the acceleration of objects falling to the Earth. Students should perform simple activities to confirm this claim. Videos of David Scott demonstrating this with the Hammer and Feather experiment on the Apollo 15 mission can be found on YouTube, where air resistance is absent. They will see mathematical reasoning for this in later physics classes;
- gravitational forces act through materials (it works through a table to hold a cup in place). A rock being pulled to the ground only stops at the ground because the ground pushes back (Newton's third law);
- overcoming the force of gravity requires a stronger push or pull in the opposite direction.

Table 13. Unit and SI Unit

Concept	Symbol	Unit and SI Unit	SI Derived Units
force	F	Newton (N)	1N = 1 $kg \cdot m \cdot s^{-2}$
mass	m	kilogram (kg)	-
acceleration	a	-	m/s^2 or $m \cdot s^{-2}$

CK3.1

CONTENT KNOWLEDGE

CK 3.2	*Learners are expected to ...*					
	analyze energy transformations in mechanical systems.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating

Achievement Indicators

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

a use the following vocabulary appropriately: conservation of energy, kinetic energy, potential energy, velocity;

b compare and contrast kinetic and potential energy;

c identify examples of types of energy (kinetic, gravitational potential, elastic potential, chemical potential, thermal, light, sound and electrical energy);

d use diagrams to illustrate energy transformations within a system; and

e apply $KE = \frac{1}{2}mv^2$ and $PE = mgh$ to calculate quantitative changes in energy within a closed system.

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

ELABORATIONS

To meet PK 4 students will design a mechanical system to perform a task. This will require an understanding of how to control the input and transfer of energy within the system. During CK 3.1 students prepare for this task by developing conceptual understanding of motion and the relationship between force, mass and acceleration. CK 3.2 is a continuation of this learning as students consider that all types of energy (e.g., thermal, chemical, gravitational, elastic, sound) can occur as either kinetic or potential energy and examine ways to control energy transformations.

Potential Energy

Potential energy (from Latin potential) is often referred to as "stored" energy. It has the potential to be converted to kinetic energy. Changing the position, shape, or composition of an object changes its energy. Students may have the misconception that objects at rest do not have energy. However, everything has energy. An unstretched rubber band, a container of fuel, and stationary ball all have energy. These stationary items have potential energy due to their position, shape, and composition. A spring that is compressed and a stretched rubber band have potential energy relative to their relaxed state. A book placed on a table has potential energy relative to the floor.

Gravitational potential energy of an object is increased with an increase in an object's height above a reference (such as Earth's surface). When a force is applied to push or pull an object away from the pull of the Earth's gravity its gravitational potential energy is increased. The change in potential energy (PE) it gains can be quantified by applying the mathematical formula:

$PE_{grav} = mgh$ where PE is gravitational potential energy (J), m is the mass of the object (kg), g is gravitational acceleration ($9.81\ m/s^2$) and h is height of object (m).
This is a proportional relationship that students can investigate using simple activities to determine that doubling the height or mass will double the change in potential energy which can then be converted to kinetic energy.

Kinetic Energy

Kinetic energy is reflected by movement of an object. CK 3.1 addressed Newton's first law which states that objects remain at rest unless a push or a pull (a force) causes them to move. Once in motion the object continues in the same direction and speed (together known as velocity) unless an unbalanced force causes this to change. Students should connect the idea that when an unbalanced force is applied it can cause changes in kinetic energy which is seen by changes in the motion of an object. Changes in kinetic energy of an object are equivalent to the amount of work done on an object which is related to the net force. The concept of work (i.e., force x displacement) will not be examined during Science 421A.)

Kinetic energy (KE) is quantified by the mathematical formula:
$KE = \frac{1}{2}mv^2$, where KE is kinetic energy (J), m is the mass of the object (kg), and v is velocity (m/s) of the object.
For teacher information forces, acceleration, and velocity are considered "vectors" because they have magnitude and direction. Velocity (m/s) is a measure of the speed and the direction of an object. The rate of change of velocity is described as acceleration (m/s^2) which is addressed by CK 3.1.

Conservation of Energy

In an isolated system, one where energy cannot enter or leave, the amount of energy remains constant. However, Energy can be converted to other forms. Students should be able to identify and illustrate these energy conversions.

Decisions and Perspectives

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.					
	Remembering	Understanding	Applying	Analysing	**Evaluating** ■	Creating

Achievement Indicators

Learners who have achieved this outcome should be able to …

a use the following vocabulary appropriately: benefit, ethics, perspective, risk;

b identify a technology or a scientific development that addresses a human need or practical problem (e.g., plastics, fertilizers, energy sources, pesticides, processes to purify water and treat waste, food preservatives, medical treatments/preventative measure (vaccines), CRISPR technology, the computer chip, nanotechnologies, mass production technologies, artificial intelligence, robotics);

c recognize that scientific and technological developments can have both risks and benefits;

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

e evaluate the advantages and disadvantages of a technological or scientific development using an evaluative technique such as plus-minus comparison, risk-benefit analysis, or SWOT analysis (strengths, weaknesses, opportunities, threats);

f identify their personal beliefs and bias related to a scientific or technology advancement (e.g., application of genetic engineering, mass production and disposable products, green versus non-green energy, natural versus processed food);

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

h project the consequences (e.g., on the community, economy, environment, public health, etc) of proposed decisions beyond individual impact;

i recognize that multiple perspectives can be correct;

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

k provide scientific evidence and reasoning to support an opinion.

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

ELABORATIONS

The purpose of DP 1 is to encourage the development of critical thinking, communication, and citizenship. It is a paradox that while science and technology help us solve problems, they often create new ones. Science focuses on answering why and how something works, it is unable to answer "should we"... which is the basis of ethical decisions—ones that we make for the greater good. Science and technology have enabled us to create materials that last for thousands of years, use limited resources at unprecedented rates, and even change the genetic codes of species. Decisions about applying what we learn from science have the potential to impact everyone directly or indirectly. As such, the ethical application of science is the responsibility of society as a whole and an overarching question for us is, "Just because science enables us to, should we?"

Prior to making a decision, students will need to analyze the scientific development in terms of its possible benefits, risks, degree of uncertainty, and unintended impacts (both negative and positive). The process of this analysis can begin by having students generate questions that can guide the analysis. Modeling the use of a decision making tool such as the chart below can help students learn to approach decision making systematically.

Benefits (e.g., environmental, health, economic)	**Risks** (e.g., environmental, health, economic)
ARTIFICIAL INTELLIGENCE	
Possible unintended impacts (+/-)	**Individual perspectives**

Figure 15. Modeling using a decision making tool.

Students should understand that with any new development there will be a level of uncertainty about the outcome due to the fact that there are usually many inter-related variables, each which can result in an unintended effect. Most decisions made about accepting a new science or technology involve weighing the risk against the benefits. As well, alternatives and the risks associated with those alternatives are often considered as part of the process.

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

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

Students will soon learn that deciding on the "right" course of action is not always as straightforward as it seems; multiple perspectives can be correct. As globalization results in our close proximity in the real and virtual world, it is imperative that we encourage open-mindedness in our students. We need to help them understand that considering issues from other points of view can provide us with alternative solutions to a problem.

Decisions and Perspectives

DP 2	*Learners are expected to ...*					
	demonstrate skills and characteristics necessary for career pathways related to science, technology, engineering, or math.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
			■			

Achievement Indicators

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

a discuss the following concepts: career, mind-set, STEAM, success;

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

c challenge stereotypes associated with scientists and engineers;

d engage in effective and respectful communication and collaboration;

e ask questions and pursue answers;

f demonstrate skills and characteristics related to goal-setting and time-management;

g demonstrate positive work ethic;

h demonstrate the ability to encounter challenges with increasing independence, maturity, flexibility, creativity, and persistence; and

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

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

ELABORATIONS

To meet the essential graduation competency (EGC) Career-Personal 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." While some occupations in the area of science and technology are yet to be defined and are constantly evolving, it is accepted that in addition to cognitive skills, students will need to develop inter- and intrapersonal skills.

Selected Habits of Mind
- Curiosity
- Skepticism
- Integrity
- Persistence
- Resilience
- Creativity
- Innovation
- Diligence
- Flexibility
- Reflection

The Canadian Career Development Foundation (CCDF) defines career development as "the life-long process of managing learning, work, leisure, and transitions in order to move toward a personally determined and evolving preferred future." Inviting an individual from a STEM (science, technology, engineering, or math) discipline to speak to the class about their career pathway, early interests and activities, can help students recognize that a careers is not simply an occupation, but a purposeful life journey that involves meandering, maneuvering, finding meaning, and building momentum.

Late adolescence is a time of increasing autonomy and self-discovery leading to identity formation. The high school learner seeks relevance and connection between life outside school and the curriculum, develops their own voice, and is concerned about future plans. It is an appropriate time to help them make connections between knowledge, skills, and characteristics (or habits of mind) that lead to success in the classroom and any other walk of life.

A strength-based approach is a learning philosophy that recognizes and values what the learners can do rather than what they cannot. It does not ignore deficits but does focus upon growth from strengths and abilities. Students should be provided with formative feedback and opportunities to improve STEM career-related skills throughout the course. Teachers may wish to co-construct criteria with students and use observations, conversations, and student self-assessments as part of the evaluation of this outcome.

Some students may have their own problem-solving strategies, however science teachers should help students reflect upon them and expand their repertoire. One strategy that could be transferred from CEO401A is "My Board of Directors" (see What are my opportunities?—myplanpei.ca). This resilience strategy has students identify a support network of people whom they can turn to for advise, support, or expertise. Their network can include teachers, peers, counselors, or family members and evolves over time. Advice from their board may be directed towards such things as time management, academic challenges, test anxiety, staying motivated, preparing for life after high school, issues outside of the classroom.

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

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).

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.

Glossary

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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