CHM621A

SCIENCE

Grade 12 Chemistry

Curriculum Guide

Prince Edward Island
CANADA

Acknowledgements

The Prince Edward Island Department of Education and Early Years (DEEY) gratefully acknowledges the contributions of the following individuals and groups in the development of the Prince Edward Island CHM521A and CHM621A Curriculum Guides.

Chemistry Curriculum Development and Pilot Committee

Hadley Sealy - Colonel Gray High School
Ian Gillis - Three Oaks Senior High
Krista MacDonald - Souris Regional School
Lloyd Theuerkauf - Bluefield High School
Louis Andrew - Kensington Intermediate Senior High
Matthew Killeen - Kinkora Regional High School
Nancy Getson - Westisle Composite High
Philip MacDonald - Montague Regional High School
Rosanne MacLeod - Charlottetown Rural High School
Tracy McGee - Morell Regional High School

Jonathan Hayes - Secondary Science Innovation Leader, DEEY

Prince Edward Island
Department of Education and Lifelong Learning
250 Water Street, Suite 101
Summerside, Prince Edward Island, Canada, C1N 1B6
Tel: (902) 438-4130. Fax: (902) 438 4062

Implemented 2021
(Updated 2024)

Table of Contents

Table of Contents

List of Tables and Figures

List of Tables

List of Figures

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 science 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 science program;
- informs both educators and members of the general public about the philosophy and scope of science education for the senior high school level in Prince Edward Island;
- promotes the effective learning and teaching of science 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.

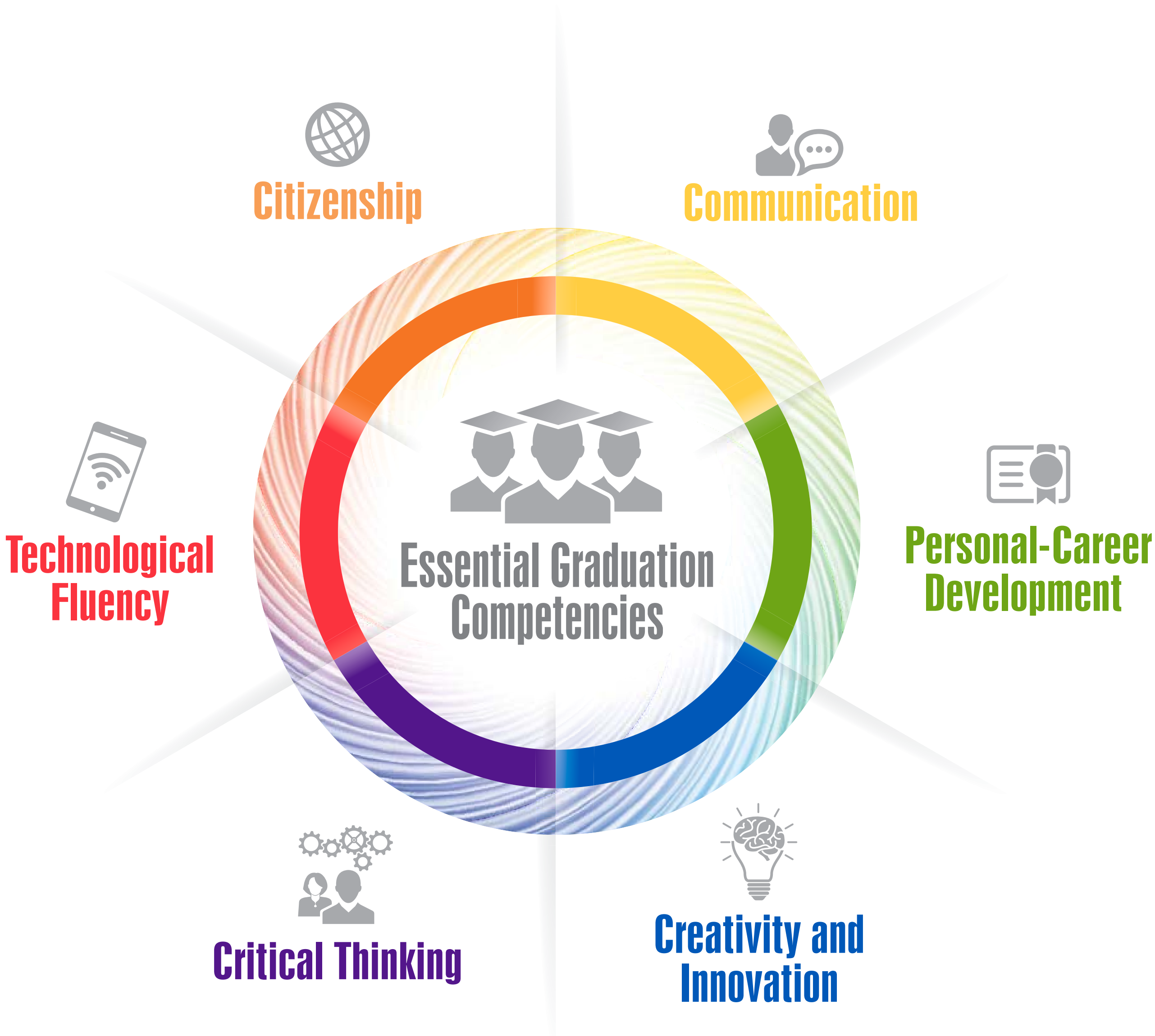


Figure 1. *Essential Graduation Competencies*

Curriculum Design

Essential Graduation Competencies—Definitions

[redacted]

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.

Curriculum Design

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: perform
cognitive process: APPLYING

CK1.3 perform calculations involving the molar solubility of a pure substance in water.

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)

Content Knowledge

Specific curriculum outcome (SCO)

CK 2.1	*Learners are expected to ...*					
	perform calculations involving the molar solubility of a pure substance in water.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
			■			

Cognitive process level for this particular SCO

Achievement Indicators

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

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

a calculate the concentration in mol/L or molarity, M, of stock solutions based on mass and/or moles of the solute (or solute ions) and volume of the solution, and vice-versa;

b perform dilutions and dilution calculations; and

c graph and interpret a standard curve to identify the concentration of an unknown solution.

Essential Graduation Competencies Map

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

64 GRADE 12 CHEMISTRY - CHM621A

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

Science Learning Environment

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.

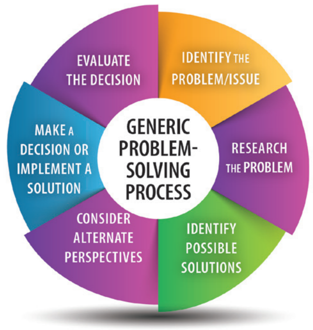


Figure 3. *Generic Problem Solving Process*

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.*

Science Learning Environment

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.

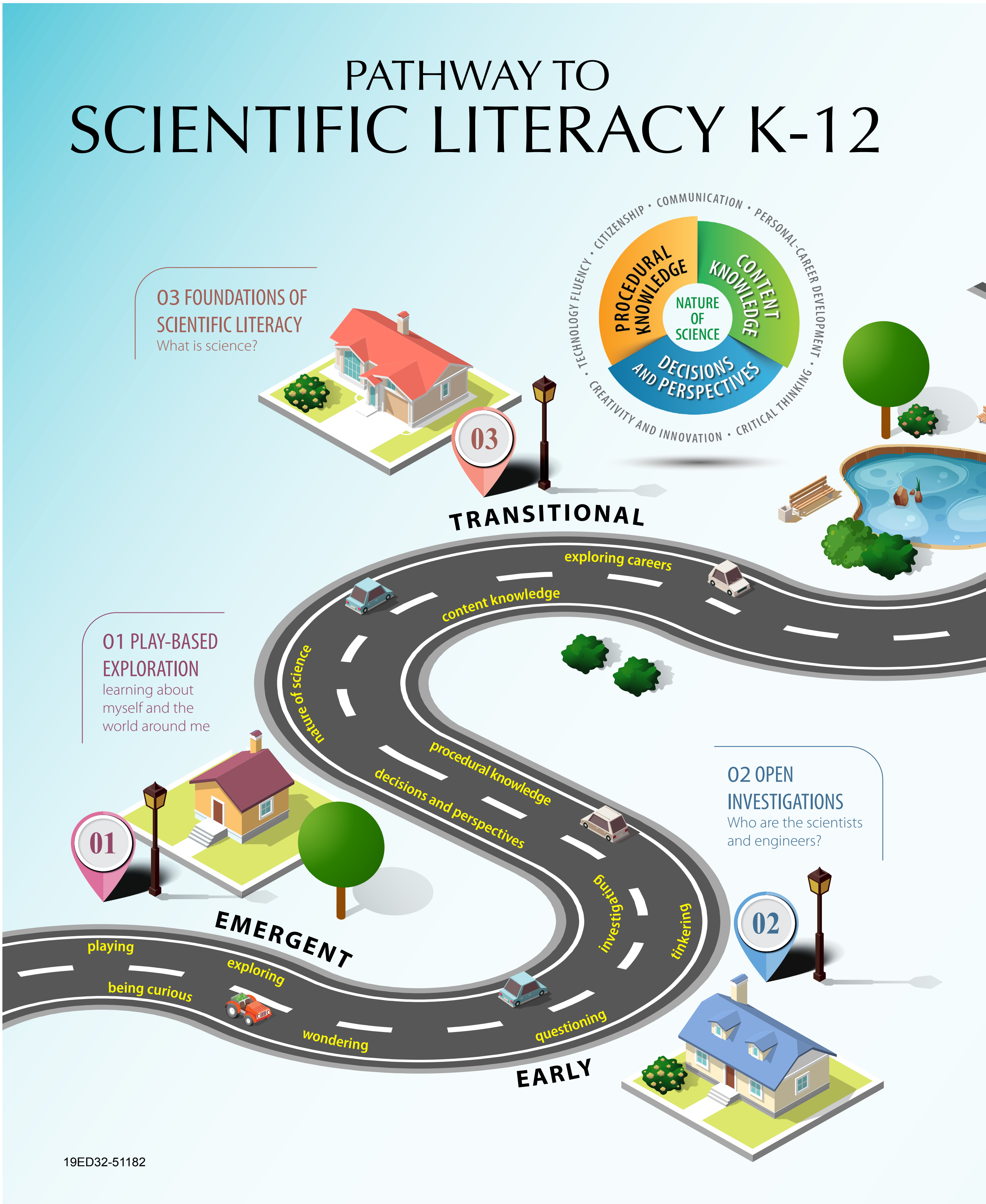
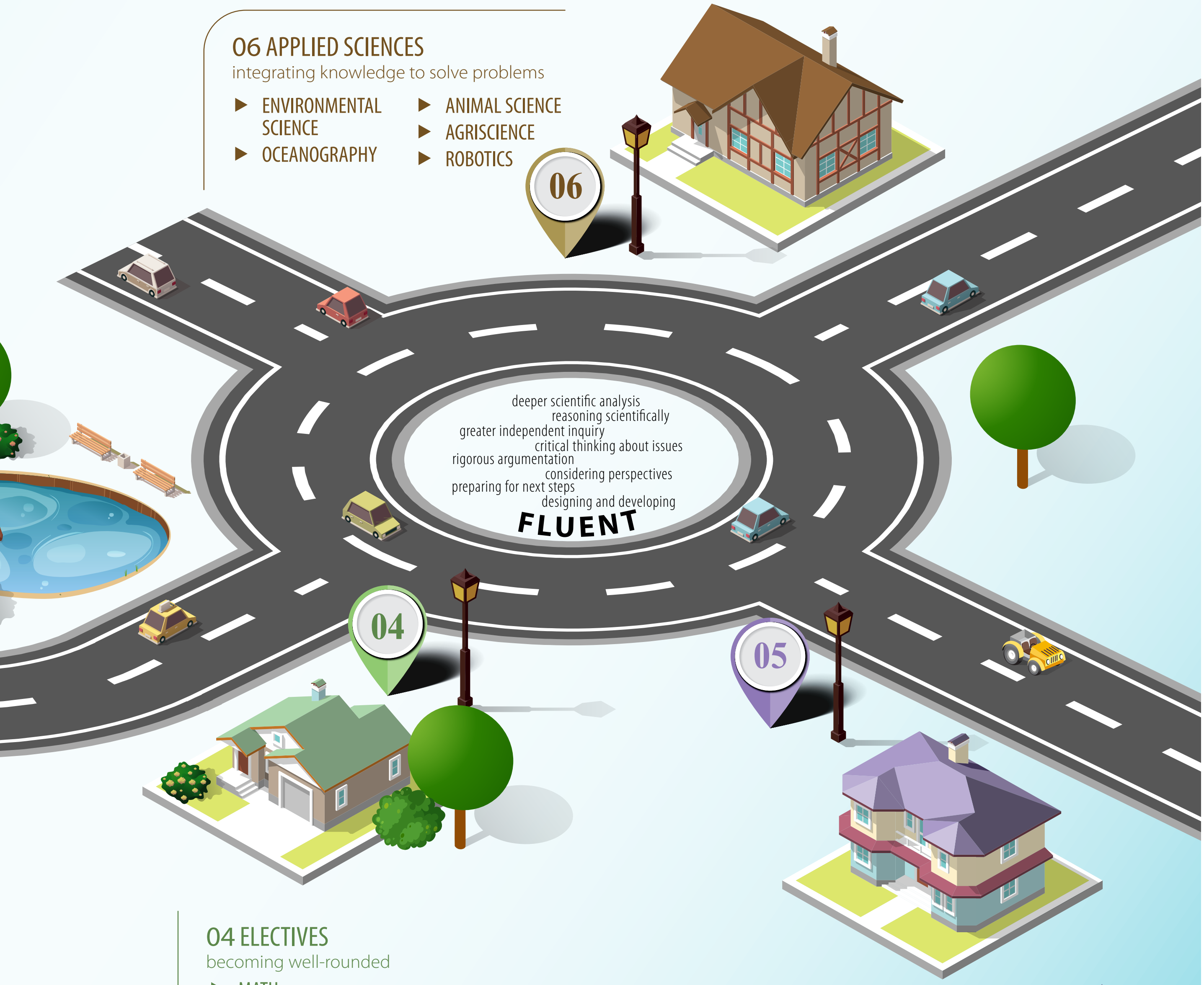


Figure 6. *Pathways to Scientific Literacy*

06 APPLIED SCIENCES

integrating knowledge to solve problems

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



04 ELECTIVES

becoming well-rounded

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

05 CORE DISCIPLINES

digging deeper into content knowledge

- BIOLOGY
- CHEMISTRY
- PHYSICS

Overview

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

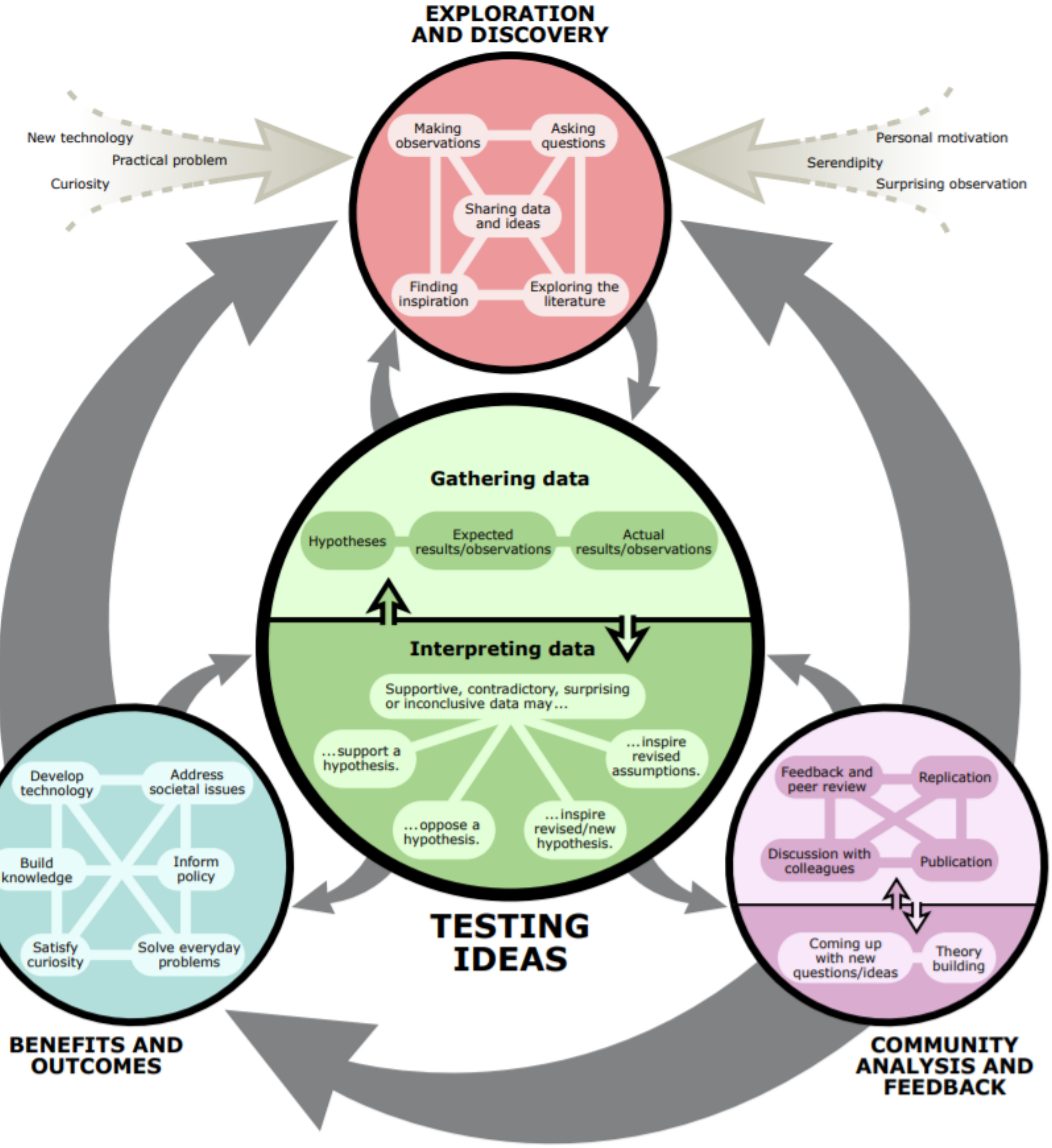


Figure 7. *How Science Works (University of California Museum of Paleontology 2016)*

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?

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

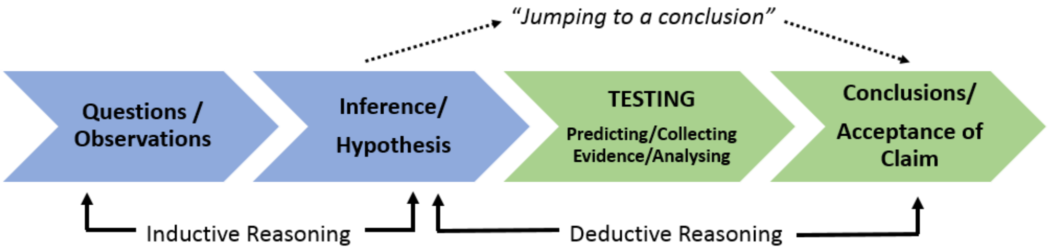


Figure 8. *Scientific Reasoning*

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

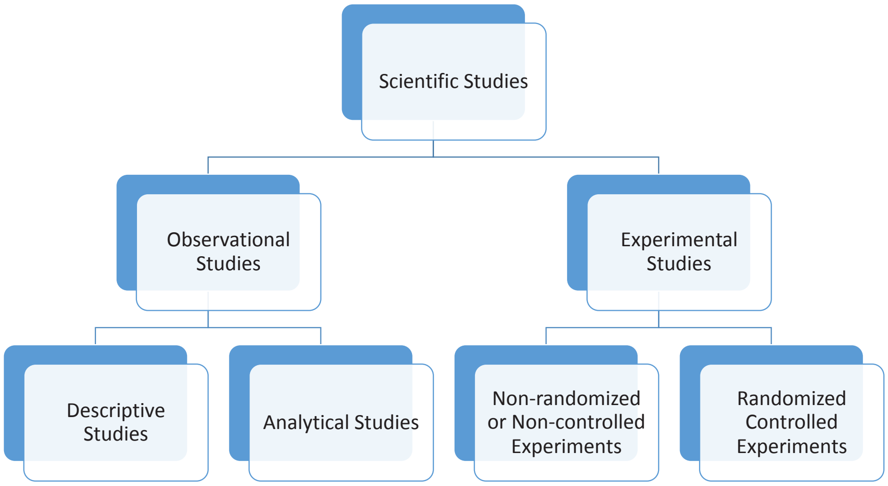


Figure 9. *Classification of Scientific Studies. Adapted from Oleckno, 2002*

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

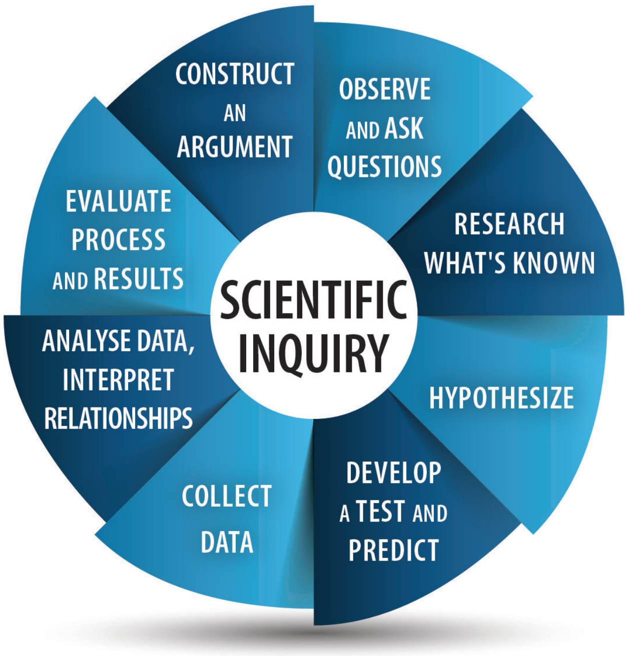


Figure 10. *Scientific Inquiry Process Wheel*

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)*

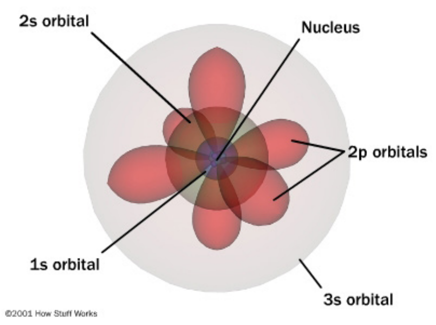


Figure 11. *Quantum Mechanical Model of the Atom*

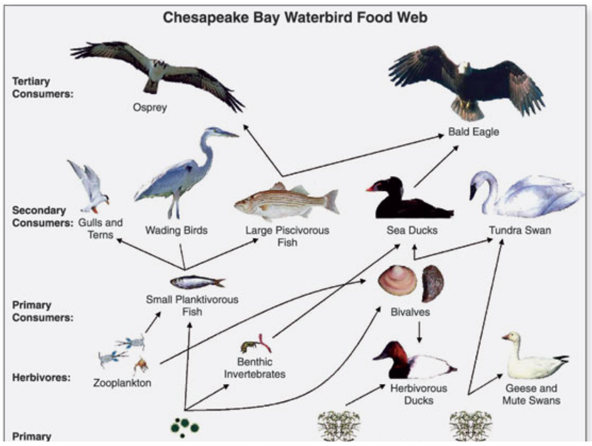


Figure 12. *Energy Flow in a Food Web (Perry 2019)*

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.

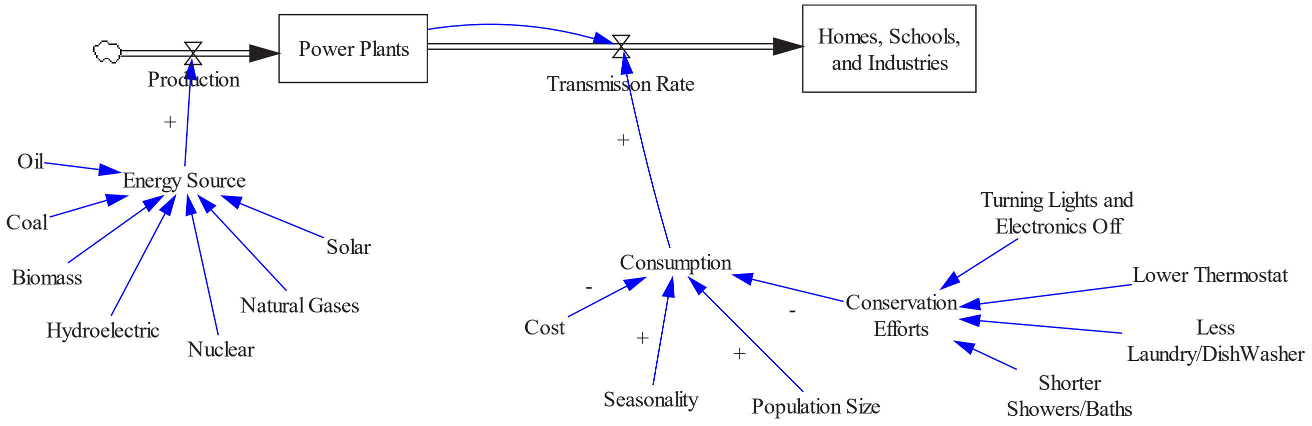


Figure 13. *Stock and Flow Conceptual Model*

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.

CHM621A

SCIENCE

Grade 12 Chemistry

Curriculum Guide

Prince Edward Island
CANADA

Chemisty 621A Course Overview

Course Description

This course provides an opportunity for students to develop scientific literacy through the study of thermochemistry; solutions, kinetics, and equilibrium; acids and bases; and electrochemistry. These topics, along with procedural knowledge, provide the content and skill framework that will be used to engage students with the processes of scientific literacy, (inquiry, problem solving, decision making), and continued development of the essential graduation competencies. Chemistry 621A is a university preparatory course that builds on the foundational learning developed in Chemistry 521A.

Outcome Summary

The outcomes of CHM621A are categorized into four scientific literacy foundations (Nature of Science, Decisions and Perspectives, Procedural Knowledge and Content Knowledge). Table 7 below shows the summary of specific curriculum outcomes for CHM621A. Each specific curriculum outcome with its related achievement indicators and elaborations can be found in the following section.

Table 5. Summary of Curriculum Outcomes

GCO	Code	Specific Curriculum Outcomes
Nature of Science; Decisions and Prsepctives	NoS 1	analyse the development of a technology related to Chemistry.
	DP 1	evaluate, from multiple perspectives, the risks and benefits of a technology related to Chemistry to society and the environment.
Procedural Knowledge	PK 1	apply knowledge and understanding of safe laboratory protocols and procedures.
	PK 2	apply appropriate techniques, procedures, and technologies for collecting and analysing data in order to solve problems.
	PK 3	use uncertainty in data measurement and data processing.
	PK 4	evaluate scientific phenomenon using argumentation.
	PK 5	design an experiment identifying and controlling major variables.
	PK 6	use appropriate language and formatting conventions to effectively communicate plans, procedures, data, results, and conclusions of research and experimentation.
Content Knowledge	CK 1.1	explain thermochemistry and the terms associated with the study of thermochemistry.
	CK 1.2	determine the change in energy involved during changes of state and temperature.
	CK 1.3	determine the changes in energy involved during chemical reactions.
	CK 2.1	perform calculations involving the molar solubility of a pure substance in water.
	CK 2.2	use collision theory to explain factors affecting reaction rate.
	CK 2.3	evaluate chemical equilibrium to determine concentrations, constants, and to predict shifts.
	CK 3.1	classify substances as acids or bases based on the Arrhenius and Brønsted-Lowry definitions.
	CK 3.2	apply the concept of equilibrium to acid-base reactions.
	CK 3.3	evaluate acid-base equilibrium reactions.
	CK 4.1	describe the chemical changes that occur during redox reactions.
	CK 4.2	balance redox reactions in acidic, basic, and neutral solutions using the half reaction method
	CK 4.3	analyse the functioning of electrochemical cells.

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 CHM621A

Domain/GCO	Remember	Understand	Apply	Analyse	Evaluate	Create	GCO Weight
Nature of Science; Decisions and Perspectives				NoS1			**10%**
					DP1		
Procedural Knowledge			PK1				**25%**
			PK2				
			PK3				
					PK4		
						PK5	
			PK6				
Content Knowledge		CK1.1					**65%**
					CK1.2		
					CK1.3		
			CK2.1				
			CK2.2				
					CK2.3		
			CK3.1				
			CK3.2				
					CK3.3		
		CK4.1					
			CK4.2				
				CK4.3			

Reporting Structure

Nature of Science, Decisions & Perspectives	7	(10% of 70)
Procedural Knowledge	18	(25% of 70)
Content Knowledge	45	(65% of 70)
Major Assessments	30	(Reflective of Domain Weightings)

NATURE OF SCIENCE: INNOVATION

NoS 1	*Learners are expected to ...*					
	analyse the development of a technology related to Chemistry.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating

Achievement Indicators

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

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

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

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

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

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

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

Essential Graduation Competencies

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

ELABORATIONS

Outcome NoS1 can be addressed independently, or in conjunction with complimentary outcome DP1. Furthermore, this outcome may be addressed via a project, either individually or in groups, where students present their research in the form of a “speakers series” or "video series" that is scheduled to occur throughout the course.

Students should analyse the design of their technology and the way it functions. To explain how their technology improved over time students should look at historic iterations of their technology to identify improvements/efficiencies resulting from the evolution of scientific knowledge. Furthermore, emerging technologies may have revolutionized how the scientific community thinks about the technology production and/or use. For example, a breakthrough in energy storage such as the lithium-ion cell or hydrogen fuel cell technology may be the crucial ingredient in favor of renewable energy usage as opposed to fossil fuels. Guiding questions may assist student research. For example, the following guiding questions may be used to direct research on an energy technology:

- Analyse the design of your technology. How does it work?;
- What is the most common method of producing/transmitting/storing your energy?;
- Outline the development of your technology. How was it improved over time?;
- What is the magnitude of the energy involved with your technology?; and
- Were there emerging technologies that were complementary to the development or use of your energy technology?

DECISIONS AND PERSPECTIVES: RISK/BENEFITS

DP 1	*Learners are expected to ...*					
	evaluate, from multiple perspectives, the risks and benefits of a technology related to Chemistry to society and the environment.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
					■	

Achievement Indicators

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

a define technology as the application of scientific knowledge;

b understand that multiple perspectives exist in relation to the risks and benefits of technology;

c determine, from multiple perspectives, the risks and benefits of a particular technology on the environment;

d determine, from multiple perspectives, the risks and benefits of a particular technology on society; and

e evaluate the sustainability of the technology (social, economic, environmental).

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

ELABORATIONS

Outcome DP1 can be addressed independently, or in conjunction with complimentary outcome NoS1, at various times during the progress of this course. This outcome goes beyond analyse as it requires a judgement to be made resulting from an evaluative process.

Although science informs society by answering questions related to why and how something works, it is unable to answer "should we..." questions, which are the basis of ethical decisions. In addition to the knowledge, skills and attitudes developed in science courses, part of the end goal of developing scientific literacy is to enable students to make ethical decisions about what is reasonable to do or believe regarding scientific and technological ideas, issues, or developments. These decisions may have personal, societal, environmental, economic, or political impacts. Specific curricular outcome DP1 addresses the evaluative component of the decision-making process by asking students to examine the possible advantages (benefits) and disadvantages (or risks) of science and technology and then expects students to make justified decisions based on evidence and reasoning with consideration of varying perspectives.

Using an energy technology as an example, students could analyse factors that may have played a key role in catalyzing the development of an energy technology in order to explain why the technology developed or improved over time. Sustainability (environmental, economic, societal), climate change, and other factors such as supply should be considered by students while performing research on their technology. For example, increased efficiency of a renewable energy in addition to a lower initial cost may be important contributing factors to the selection of a particular energy source as a viable alternative over others such as fossil fuels. Finite resources (petroleum products), societal pressure involving a demand for renewable energy, or climate change may have been the driving force in the development of an energy technology. Guiding questions may assist student research. For example, the following guiding questions may be used to direct research on an energy technology:

- What are the characteristics of a good energy source? Would an individual who lives in a different location, societal context, or economic situation agree with you?
- What makes a technology a good choice from your perspective? Would others agree?
- In terms of the environment (local/global), what are some advantages of an energy technology? Some disadvantages?
- In terms of society what are some advantages (health, economic, safety, etc.) of an energy technology? Some disadvantages?
- What are some constraints in the development of the technology/process that may have resulted in trade-offs during development?
- Is this technology sustainable? How might it help to achieve climate change targets?

Procedural Knowledge: Safety

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

Achievement Indicators

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

- a interpret Workplace Hazardous Materials Information System 2015 (WHMIS 2015) pictograms and labels;
- b ensure the safety of self and others by understanding the general safety protocols, procedures, and hazards;
- c understand the safety protocols, procedures, and hazards specific to the activity being performed to ensure the safety of self and others; and
- d apply appropriate protocols and procedures to acquire, use, and dispose of materials and equipment safely.

Essential Graduation Competencies

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

ELABORATIONS

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

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

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

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

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

Procedural Knowledge: Experimentation

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

Achievement Indicators

Learners who have achieved this outcome should be able to …

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

b use appropriate data analysis tools, including spreadsheets, for data analysis;

c use appropriate techniques for data collection and data analysis; and

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

Essential Graduation Competencies

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

ELABORATIONS

It is important that students not only know how to use technologies (electronic balance) and techniques (massing by difference) that are common to science but are also able to apply and communicate appropriate techniques, procedures, and technologies specific to the topic being investigated in order to solve problems. Students must attain a level of understanding that allows them to act flexibly with the procedural knowledge that they acquire.

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

Common Core Laboratory:

Lab 1: Heat Capacity of a Metal (Thermochemistry)
Lab 2: Heat of Reaction / Hess' Law (Thermochemistry)
Lab 3: Stock Solution & Dilution Series / Colorimetry (Solutions)
Lab 4: Rate of Reaction (Kinetics)
Lab 5: L'Chatelier Principle (Equilibrium)
Lab 6: Acid/BaseTitration (Acid-Base)
Lab 7: Electrochemical Cell (Electrochemistry)

The depth of this outcome goes beyond understand and use. Students are expected to apply (and communicate) the techniques and procedures learned through experimentation. Consequently, the following question related to a common core lab procedure further elucidates the expectation for assessment of outcome PK2.

Assessment Item:
You are provided with a sample of a metal that is claimed to be pure gold. Describe a procedure learned in this course that can be used to test this claim.

Answer Details: It is expected that a student would explain that every substance has a unique specific heat capacity; therefore, a pure substance can be identified by comparing the literature value for specific heat capacity to an experimental value. The student would then be required to write a procedure to find the specific heat capacity of the metal and compare it to that of pure gold.

Note: As density was not a procedure learned in Chemistry 621A (was learned in prior grades) it may not be used as a procedure to support the claim.

Please Note: for efficiency purposes, SCO PK5 may be addressed by incorporating experimental design in any of the common core laboratories identified above.

PROCEDURAL KNOWLEDGE: UNCERTAINTY

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

Achievement Indicators

Learners who have achieved this outcome should be able to …

a distinguish between accuracy and precision;

b understand random and systematic error and their sources;

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

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

e manipulate subject specific algebraic expressions to isolate any variable;

f estimate and calculate an unknown quantity using known quantities; and

g process data with precision that shows appropriate significant figures.

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

ELABORATIONS

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

Random error results from the imprecision of measuring devices leading to values measuring above or below the expected value. We often run multiple trials or use more precise equipment to mitigate random error.
Systematic error results from improper experimental setup leading to values measuring always above or always below the expected value. Examples of systematic error would be a poorly calibrated instrument or a poorly controlled experiment. Multiple trials will not mitigate systematic error.

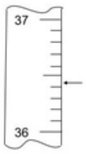
Evaluating the extent of scientific errors is important since errors directly impact the quality of evidence used to support the final conclusion. Students should look for scientific errors that affect accuracy and precision. Scientific errors are accepted as an inherent part of science and reported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

Table 7. Types of Error

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

Accuracy and precision are often used interchangeable; however, in science they have very specific meanings. Students should understand accuracy as how close a measure value is to the expected value, whereas precision relates to how close measured values are to each other. Specifically, precision dictates the significant figures in a measured value and is represented by uncertainty values, either as absolute or percent uncertainty. Students are expected to record all measured values with their associated uncertainty. Digital equipment and some analogue devices provide the percent or absolute uncertainty values; however, many analogue devices do not. The simplest way to express uncertainty of an analogue scale is to use the Least Count method which reflects the smallest division on the scale. Often this method over exaggerates the actual uncertainty so a Fractional Least Count method can be used. It is important for students to note that there are many ways to account for uncertainty and that the big idea is that there is uncertainty in measurement and that a reasonable attempt to account for it must be employed.

Table 8. Uncertainty in Measurement

Example		Least Count	½ Least Count	⅕ Least Count
	Burette scale having the mL divided by 10 (0.1 mL increments shown)	36.4 mL ± 0.1 mL	36.43 ± 0.05 mL	36.43 ± 0.02 mL
		(notice that the decimal place of the value is consistent with the uncertainty; the 3/100th was estimated with the Fractional Least Count method)		

Precision in data processing in 521A/621A courses is limited to the rules for mathematical operations involving significant figures.

PROCEDURAL KNOWLEDGE: ARGUMENTATION

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

Achievement Indicators

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

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

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

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

d discuss potential sources of error (random and systematic) in experimental data;

e argue the directional impact of error on results;

f argue which sources of error most likely had major/minor effect on results;

g explain ways to adjust experimental procedure to mitigate uncertainty or the use of controls to strengthen claims; and

h discuss limitations of the evidence provided (weaknesses in the methodology used to answer the original question) including possible sources of bias.

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

ELABORATIONS

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

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

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

Table 9. Claim, Reasoning, Evidence Writing Frame Sample

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

PROCEDURAL KNOWLEDGE: EXPERIMENTAL DESIGN

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

Achievement Indicators

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

a formulate relevant questions to investigate;

b formulate hypothesis and make informed predictions;

c identify and control major variables;

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

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

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

ELABORATIONS

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

This particular outcome focuses solely on the experimental design components articulated in the achievement indicators; however, in addition to the other PK outcomes it is particularly recommended that specific curriculum outcome PK 4 is addressed to assess student evaluation of their experimental design.

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 were expected to analyze and evaluate the design of experiments more deeply. Criteria used to evaluate science investigations include reproducibility, repeatability, reliability, accuracy, and precision.

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

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

Procedural Knowledge: Communication

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

Achievement Indicators

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

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

b use appropriate numeric and symbolic modes of representation to report data, the error associated with measured values (+/- range), and units of measure;

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

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

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

ELABORATIONS

The organization and style of scientific writing 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 6 is the quality or clarity of writing based on criteria such as word choice, organization, fluency, and mechanics. To develop proficiency with technical writing, students can be provided with opportunities to 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.

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

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

The use of exemplars and gradual release of responsibility for learning ("Instructional Strategies" p.34) to elucidate appropriate language and style conventions are recommended as instructional strategies.

CONTENT KNOWLEDGE: THERMOCHEMISTRY

CK 1.1	*Learners are expected to ...*					
	explain thermochemistry and the terms associated with the study of thermochemistry.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
		■				

Achievement Indicators

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

a define temperature, heat, thermal energy, potential energy, kinetic energy, endothermic, exothermic, specific heat, bond energy, enthalpy, molar enthalpy, and thermochemistry;

b distinguish between temperature, heat, and enthalpy;

c distinguish between a closed system, open system, and isolated system; and

d explain the Law of Conservation of Energy (1st Law of Thermodynamics).

Essential Graduation Competencies

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

ELABORATIONS

As an introduction, ask students for everyday examples involving endothermic and exothermic changes. Examples might include heating and freezing of ice, hot and cold packs, evaporation and condensation of water. This discussion could lead into a definition of thermodynamics and thermochemistry and the ability to differentiate between endothermic and exothermic changes. Students could then be introduced to a discussion of the Law of Conservation of Energy (1st Law of Thermodynamics). Scenarios could be provided where students have to identify the system, the surroundings, and the direction of the energy flow. Sufficient opportunity should be provided for students to pose questions about types of systems and the energy changes that occur within them.

Students often hold the naive conception that temperature and thermal energy are equivalent. To illustrate the difference between thermal energy and temperature have students complete a Predict-Explain-Observe (PEO) activity involving heat transfer between water and two dissimilar metals of the same mass. This demonstration should also provide a valuable context to assist with the development of the Law of Conservation of Energy and the identification of system and surroundings.

Bond energy, enthalpy, molar enthalpy, and heat of reaction should be discussed; however, these will be referred to again later in this unit.

CONTENT KNOWLEDGE: THERMOCHEMISTRY

CK 1.2	*Learners are expected to ...*					
	determine the change in energy involved during changes of state and temperature.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
					■	

Achievement Indicators

Learners who have achieved this outcome should be able to …

a identify if the system undergoing a physical change is exothermic or endothermic;

b draw and interpret heating/cooling curves for the energy change in a system;

c write and interpret thermochemical equations for changes in state;

d determine the specific heat capacity of a substance;

e determine the molar enthalpy of a substance;

f determine the heat gained or lost from a system resulting from a change in temperature using the formula $q=mC\Delta t$, and vice versa; and

g determine the heat gained or lost from a system resulting from a change in state using the formula $q=n\Delta H$.

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

ELABORATIONS

Students should investigate heating, cooling, and phase changes in terms of forces between particles, particle movement, heat content, and changes in potential energy. Changes to particle movement in systems in terms of change in temperature could be introduced. Changes in potential energy in matter should be discussed when calculating energy involved in changes in state.

Students should calculate specific heat capacity and perform calculations involving specific heat capacity. Students should qualitatively and quantitatively describe the resulting temperature when two substances are mixed together. The relatively high specific heat capacity of water should be investigated. Invite students to relate the importance of this quantity to issues such as climate control, heat delivery in homes, and coolant in vehicles and homes.

Students should define the molar enthalpy of various physical processes (soln, vap, cond, fus, freez). Students should calculate the total heat for a multi-step process such as the heat required to convert 50 g of ice at –20°C to steam at 120°C. Students could draw and label a heating/cooling curve which shows changes in kinetic and potential energy. Teachers might discuss with students the motion of particles as the substance undergoes a temperature or state change and relate each change to the kinetic theory of matter. It is suggested that the student use the formulas $q = mc\Delta T$ for changes in kinetic energy (change in temperature), and $q = n\Delta H$ for changes in potential energy (changes in state).

Content Knowledge: Thermochemistry

CK 1.3	*Learners are expected to ...*					
	determine the changes in energy involved during chemical reactions.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
					■	

Achievement Indicators

Learners who have achieved this outcome should be able to …

a illustrate the changes in energy of various chemical reactions using potential energy diagrams and thermodynamic equations;

b determine the changes in energy of various chemical reactions using calorimetry data; and

c determine the changes in energy of various chemical reactions using bond energies, heats of formation values, and Hess' Law.

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

ELABORATIONS

Students should be able to identify exothermic and endothermic process from the sign of ΔH_{rxn}, from thermochemical equations, and from labelled enthalpy/potential energy diagrams. Connections should be made between these three methods of illustrating thermochemical changes. Using an exothermic reaction as an example, students could use the terms high and low to represent the energy levels of the reactants and products, respectively. The student would then identify the enthalpy change for the exothermic reaction as being negative ($\Delta H_{RXN} = H_{final}$(low) - $H_{initial}$(high) = negative), recognize that energy was lost, or released, and place the relative energy value on the product side of the thermochemical equation. Students should be able to label enthalpy diagrams given either the ΔH_{rxn} value or thermochemical equation.

Students should write thermochemical equations to represent enthalpy notation, ΔH_{comb}, ΔH_f , and ΔH_{rxn} . Students should define the standard molar enthalpy of various chemical processes (combustion, formation, reaction). Students should calculate the heat gained or lost from a system using the thermochemical equation and the reactant data. In groups, one student could calculate the heat involved from a given mass and the other could recalculate the given mass from the calculated heat term. Calculating the heat absorbed or released should be performed using the stoichiometry concepts learned in Chemistry 521A.

Students should demonstrate an understanding that there are different ways of determining ΔH_{rxn}: Hess's Law, average bond energy, enthalpy of formation, and the use of calorimeters/experimentation. Students should use the method of adding of chemical equations and corresponding enthalpy changes to compute the enthalpy change of the overall process, which is Hess's Law. Students might address the question, "Why is Hess's Law useful?" Hess's Law could determine ΔH of a reaction that otherwise might be too difficult, expensive, or dangerous to perform.

Content Knowledge2: Solutions/Kinetics/Equilibrium

CK 2.1	*Learners are expected to ...*					
	perform calculations involving the molar solubility of a pure substance in water.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
			■			

Achievement Indicators

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

a calculate the concentration in mol/L or molarity, M, of stock solutions based on mass and/or moles of the solute (or solute ions) and volume of the solution, and vice-versa;

b perform dilutions and dilution calculations; and

c graph and interpret a standard curve to identify the concentration of an unknown solution.

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

ELABORATIONS

In Chemistry 521A students explored the concept of equilibrium pertaining to solutions and quantified the concentration of a saturated aqueous solution (solubility) in #g solute/100g H_2O. Specific curriculum outcome CK2.1 extends this knowledge by articulating a method to express solution concentration for unsaturated solutions using molarity (mol/L).

Students should be able to calculate the molar concentration (molarity) in mol/L, or M, of solutions based on mass and/or moles of solute and volume of the solution and know that [ ] always implies concentration in mol/L. Students should make stock solutions in the lab of a specified concentration and volume. The solution types and concentrations could be based on solutions that may be required in further experiments for qualitative analysis (precipitate experiments, electrochemical cells, etc). Solutions should contain appropriately labelled WHMIS labels. Students could perform an experiment involving dilutions. A standard curve could be constructed from dilutions of a stock solution. The curve could be used to determine the concentration of an unknown. Various methods could be employed to detect solution concentration such as specific gravity (specific gravity vs [ ]) and light absorption (absorption vs [ ]). This is an ideal opportunity for students to use data collection and graphing technology. Students could collect data and have the software plot the corresponding graph. Using a linear regression feature, a linear equation can be obtained and used to calculate the concentration of a solution given a measured value (specific gravity, absorbance, transmittance, etc.) that is correlated to concentration.

CK2.1

Content Knowledge: Solutions/Kinetics/Equilibrium

CK 2.2	*Learners are expected to ...*					
	use collision theory to explain factors affecting reaction rate.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
			■			

Achievement Indicators

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

a state the kinetic molecular theory;

b explain collision theory;

c describe the role of the following in reaction rate: nature of reactants, surface area, temperature, catalyst, and concentration;

d use the kinetic molecular theory and collision theory to explain how various factors can affect the rate of a reaction; and

e describe a reaction mechanism and catalyst's role in a chemical reaction.

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

ELABORATIONS

Students could investigate the role of surface area, temperature, concentration, and catalyst in reaction rate by performing lab experiments. Possible experiments could be yeast and sugar solution, antacid tablets and water, metal with an acid, or baking soda with vinegar. Discussion about slow and fast chemical reactions might emphasize why it is important to control the rates of reactions. Students could explore related examples such as rust prevention and an air bag reaction. Examples of reactions from biochemistry might also be an interesting extension.

A classroom analogy could be performed where students, represent the reacting particles, demonstrate an understanding of how the frequency of "student particle" collisions can be increased and how this concept can be related to collision theory and altering reaction rates. Various classroom conditions can be altered such as the area in which the “student particles” can move (concentration), or the speed of “student particle” movement (temperature).

Students should be able to apply their fundamental understanding of the kinetic molecular theory, collision theory, and potential energy diagrams to explain the factors that affect reaction rate.

Students should describe reaction mechanisms and show how a catalyst affects the rate of a chemical reaction by providing a different reaction mechanism. Students could research and prepare reports on catalysts used in commercial or industrial applications. Students should draw and interpret potential energy diagrams for various reactions (links to SCO CK1.3). Students’ interpretations should include exothermic, endothermic, enthalpy, activation energy, activated complex, reactants, products, and ΔH. A potential energy diagram to show the effect of a catalyst on the rate of reaction allows students the opportunity to understand the role of a catalyst on the rate of reaction.

CK2.2

Given the steps of a reaction mechanism, students should be able to identify the rate determining step, reaction intermediates, and catalysts. Students should add the steps of the overall reaction taking place to show that it equals the overall reaction. The actual determination of a reaction mechanism is difficult and requires time. Students should realize that the reaction rate (fast or slow) involves many particles that must collide according to the balanced equation of a reaction mechanism step, and not the balanced overall equation for the reaction.

Students should recognize that E and ΔE are often used in potential energy diagrams instead of H & ΔH. The use of E and ΔE are practical for all situations, particularly those in which the energy absorbed/released is in a form other than heat (ex. light). However, when a reaction involves thermal energy, H and ΔH are commonly used.

Content Knowledge: Solutions/Kinetics/Equilibrium

CK 2.3	*Learners are expected to ...*					
	evaluate chemical equilibrium to determine concentrations, constants, and to predict shifts.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
					■	

Achievement Indicators

Learners who have achieved this outcome should be able to …

a demonstratean understanding of chemical equilibrium;

b predict the favourability of reactants or products in a reversible reaction on the basis of the magnitude of the equilibrium constant or equilibrium concentrations;

c write equilibrium constant expressions;

d calculate the equilibrium constant, K_c or K_{eq}, for chemical systems when concentrations at equilibrium are known;

e perform K_c calculations involving the initial concentrations, the changes that occur in each substance, and the resulting equilibrium concentrations;

f predict the favourability of reactants or products in a reversible reaction on the basis of the magnitude of the equilibrium constant or equilibrium concentrations;

g predict shifts in equilibrium by comparing the equilibrium constant (K_{eq}) to the reaction quotient (Q); and

h predict shifts in equilibrium using Le Chatelier Principle.

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

ELABORATIONS

Students should be able to write equilibrium constant expressions. They should develop an understanding that solids and liquids are not included in the equilibrium expression and that the equilibrium constant will vary with temperature.

Students should be able to calculate, and perform calculations involving, an equilibrium constant, K_c or K_{eq}, for chemical systems when (a) concentrations at equilibrium are known or (b) when initial concentrations and one equilibrium concentration are known or (c) when initial concentrations and equilibrium constant are known. These problems may require the use of the quadratic formula; however, the use of the quadratic formula can sometimes be avoided for situations involving very small equilibrium constants. Students should be able to use the quadratic equation to solve equilibrium problems.

Students could use a table or chart to help with problems involving equilibrium changes. Consider the problem: What is the K_c value for the following reaction at equilibrium, at 25°C?

$[H_2CO_3]_{initial} = 3.2 \times 10^{-2}$ M

$[HCO_3^-] = 1.19 \times 10^{-4}$ M

$[H_3O^+] = 1.19 \times 10^{-4}$ M

$H_2CO_{3(aq)} + H_2O_{(l)} \Leftrightarrow H_3O^+_{(aq)} + HCO_3^-{}_{(aq)}$

When solving this K_c problem using H_2CO_3 , students list what they know, including the concentrations and what they want to find, write the K_c expression, substitute values into the expression, and solve it.

Students should be able to solve K_c problems involving the initial concentrations, the changes that occur in each substance, and the resulting equilibrium concentrations. Using an Initial-Change-Equilibrium (ICE) chart or Initial-Reacted-Equilibrium-Concentration (IREC) table to organize their data is helpful.

Table 10. Inital-Change-Equilibrium Table

	H_2CO_3 +	H_2O ⇔	HCO_3^- +	H_3O^+
I	0.100M	--------	~0	~0
C	-1.19×10^{-4} M	--------	1.19×10^{-4} M	1.19×10^{-4} M
E	0.099881 M	--------	1.19×10^{-4} M	1.19×10^{-4} M

Students should use Le Châtelier's Principle to determine how the concentrations of reactants and products are affected after a change is imposed on a system at equilibrium. Students should explain how a catalyst and the surface area have an effect on the time it takes to reach equilibrium even though these do not cause the equilibrium to shift. They should also determine the shift in equilibrium by comparing the equilibrium constant (K_{eq}) to the reaction Quotient (Q).

It is a common misconception that a change in pressure will always affect an equilibrium. An unequal number of gaseous particles in the reactants and products are required for a change in equilibrium to be possible. It should also be noted that a change in pressure (constant volume) as the result of the addition of a gas to the reaction vessel will not shift the equilibrium if the gas is not involved in the equilibrium system (gas is not a reactant or product). The inclusion of this *inert gas* does not increase the frequency of collisions; therefore, does not affect the forward or reverse reaction rate resulting in no shift in equilibrium concentrations.

Content Knowledge: Acids & Bases

CK 3.1	*Learners are expected to ...*					
	classify substances as acids or bases based on the Arrhenius and Brønsted-Lowry definitions.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
			■			

Achievement Indicators

Learners who have achieved this outcome should be able to …

a describe Arrhenius acids/bases;

b describe Bronsted-Lowry acids/bases;

c classify substances as acids, bases, or salts, based on their characteristics, name, and formula; and

d write the formula and provide the IUPAC name for a variety of acids and bases.

Essential Graduation Competencies

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

ELABORATIONS

Students should define acids and bases operationally in terms of their effect on pH, taste, reactions with metals, neutralization reactions with each other, conductivity, and indicators. Students should conduct an experiment in an attempt to classify various chemicals into groups based on their properties using the following tests: conductivity, litmus paper, pH paper, Mg ribbon, and $CaCO_3$ chips. After summarizing the results in a table, students identify each solution as acidic, basic, neutral ionic, or neutral molecular. Students could also examine the labels on packaged food to determine which chemicals are present, look up their formulas, and do tests to determine which are acidic, basic, or neutral. The Handbook for Physics and Chemistry, The Merck Index, or Internet sites are resourse to support this work.

Students should define and identify Arrhenius acids and write ionization equations for the behavior of Arrhenius acids in water such as: $HNO_{3(l)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + NO^-_{3\,(aq)}$

Students should define and identify Arrhenius bases and understand that an Arrhenius base must ionize to produce hydroxide ions in aqueous solutions. Students should write dissociation equations for the behavior of these bases such as the following:

$NaOH_{(s)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$

$Ca(OH)_{2(s)} \rightarrow Ca_2{}^+_{(aq)} + 2OH^-_{(aq)}$

The reaction of weak bases such as NH_3 with water, which produces a basic solution, should be included in discussion to show that the Arrhenius definition needed to be adjusted to account for the fact that NH_3 acts as a base when added to water.

The Brønsted-Lowry acid-base theory should be introduced to account for non-hydroxide bases, such as a carbonate and/or hydrogen phosphate ion. Students should interpret equations in Brønsted-Lowry terms and identify the acid and base species. Examples should include:

$HCl_{(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$

$H_2SO_{4(l)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + HSO^-_{4\,(aq)}$

Students should define a Brønsted-Lowry acid and a Brønsted-Lowry base, compare the Arrhenius and Brønsted-Lowry definitions, and write single-step and overall equations for the acid-base reactions of a substance that can donate/accept more than one proton. This allows students to observe how each species acts as an acid or base.

Students should explain how some substances helped revise Arrhenius' theoretical definition of acids.
The development of the acid-base theories up to Brønsted-Lowry should be traced to show how knowledge and thinking changed to explain new observations. Students should define and identify amphoteric substances. Examples are given below:

$NH_{3(aq)} + H_2O_{(l)} \Leftrightarrow NH_4{}^+_{(aq)} + OH^-_{(aq)}$

$H_2O_{(l)} + H_2O_{(l)} \Leftrightarrow OH^-_{(aq)} + H_3O^+_{(aq)}$

$HCO^-_{3\,(aq)} + OH^-_{(aq)} \Leftrightarrow CO_3{}^{2-}_{(aq)} + H_2O_{(l)}$

In Chemistry 521A (SCO CK2.1), students were expected to use IUPAC conventions to name hydrogen/oxygen variations of common polyatomic anions (ex. NO_3^-, CO_3^{2-}, SO_4^{2-}, PO_3^{2-}, ClO_3^-,BrO_3^-, IO_3^-). This specific curriculum outcome requires that students expand on the nomenclature learned in Chemistry 521A to name acids, including those acids that result from the hydrogen/oxygen variations of common polyatomic anions.

CK3.1

Content Knowledge: Acids & Bases

CK 3.2	*Learners are expected to ...*					
	apply the concept of equilibrium to acid-base reactions.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
			■			

Achievement Indicators

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

a complete Brønsted-Lowry acid/base reaction equations illustrating the movement of a single proton;

b identify the Brønsted-Lowry acid and Brønsted-Lowry base in strong acid-base neutralization reactions;

c identify Brønsted-Lowry conjugate acid-base pairs;

d use the concept of equilibrium to identify strong and weak acids and bases; and

e write K_a or K_b expressions for the dissociation equation for weak acids or bases, respectively.

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

ELABORATIONS

Students should complete Brønsted-Lowry acid/base reactions equation illustrating the movement of a single proton. Given two reactants, students should use a table of acid and base strengths to predict the products by first identifying which reactant will act as the acid and which will act as the base.

Consider the following reactants: $HCO_3^- + HPO_4^{2-} \Leftrightarrow$?

HCO_3^- is a stronger acid and it will donate a proton to become CO_3^{2-}
HPO_4^{2-} is a stronger base (weaker acid) and it will accept a proton to become $H_2PO_4^-$

The resulting equation is:

$HCO_3^- + HPO_4^{2-} \Leftrightarrow CO_3^{2-} + H_2PO_4^-$

acid base c. base c. acid

Students should identify the Brønsted-Lowry acid and Brønsted-Lowry base in strong acid-base neutralization reactions. Students should define and identify Brønsted-Lowry conjugate acid-base pairs.

$H_2O_{(l)} + NH_{3(aq)} \Leftrightarrow NH_4^+{}_{(aq)} + OH^-_{(aq)}$
acid + base ⇔ conjugate acid + conjugate base

Students should define strong and weak acids and bases. Students should define % dissociation, K_a, and K_b and relate their values to acid and base strength. They should identify the favorability of reactants or products for an acid-base equilibrium based on the K_a values provided for reactant and product species.

Students should write appropriate K_a and K_b equilibrium constant expression from the equations, knowing that $H_2O_{(l)}$ is omitted in the equilibrium expression. For example, the K_a expression for acetic acid in water (vinegar) is shown below:

$CH_3COOH_{(aq)} + H_2O_{(l)} \Leftrightarrow H_3O^+{}_{(aq)} + CH_3COO^-{}_{(aq)}$

$$K_a = \frac{[H_3O^+][CH_3COO^-]}{[CH_3COOH]}$$

An experiment could be performed to represent the reversible nature of an acid-base equilibrium systems using an indicator. Using the chemical equations and LeChâtelier's principle (links to SCO CK2.3) the color changes could be predicted as a result of an equilibrium shift when a strong acid or a strong base is added.

CONTENT KNOWLEDGE: ACIDS & BASES

CK 3.3	*Learners are expected to ...*					
	evaluate acid-base equilibrium reactions.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
					■	

Achievement Indicators

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

a calculate the pH and pOH of an acid or base given its concentration, and vice versa;

b calculate K_a and K_b values from equilibrium concentrations, and vice versa;

c organize quantities in acid/base equilibrium using Initial-Change-Equilibrium (ICE) tables;

d evaluate acid/base equilibrium to determine equilibrium concentrations, pH, pOH, $[H_3O^+]$, $[OH^-]$, and % dissociation given initial concentration and K value;

e evaluate acid/base equilibrium to determine equilibrium concentrations, pH, pOH, $[H_3O^+]$, $[OH^-]$, and % dissociation given $[H^+]$ or pH and the K value;

f perform calculations associated with acid-base titrations;

g explain how acid-base indicators function;

h select appropriate indicators for acid-base titrations;

i distinguish between endpoint and equivalence point;

j sketch titration curves; and

k graph and interpret titration curves.

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

ELABORATIONS

Students should distinguish between the terms strong acid (or strong base) and acidic (or basic). They should identify the values of pH and pOH associated with acidic and basic solutions. Students should identify that the presence of [H_3O^+] or [OH^-] from an added strong, or reasonably strong, acid or base will not be affected to any significant extent by the self-ionization reaction for water which avoids them having to account for the [H_3O^+] or [OH^-] ions produced. Problem solving using K_w might be done here. Students could solve for either [H_3O^+] or [OH^-] using K_w at 25°C. Additional problems could include the determination of the molarity, M, of these ions. For example: calculate the [H^+] or [H_3O^+] if 5.0 g of NaOH is dissolved in 200 mL solution.

Students should calculate the value of K_a or an equilibrium concentration given all other values for the equilibrium expression. For calculations involving the equilibrium constant expression in which calculations must be performed prior to substituting values into the expression, group discussion of problem solving strategies would help students to better understand the relationships between reactant and product species, initially and during equilibrium.
An ICE chart table is a helpful method of organizing data and making the connection between reactant and product species.

	CH_3COOH +	H_2O ⇔	CH_3COO^- +	H_3O^+
I	0.100M	0	~0	
C	-x		x	x
E	0.100-x 0.100 (if "x" is negligible)		x	x

The above ICE table involves the calculation of concentration of all equilibrium species given the K_a and initial concentration. The quadratic equation may be required to solve for "x"; however, the following guide may be used for situations in which the value of K_a (or K_b) is small enough to assume that amount of acid (or base) dissociated, "x", is negligible in relation to the initial concentration of acid (or base). This simplifies the calculation by eliminating the need to use the quadratic equation.

If $\frac{[HA]}{K_a} > 500$, the change "x" in initial concentration is negligible.

If $\frac{[HA]}{K_a} < 500$, the change "x" in initial concentration is not negligible. The quadratic equation will be required.

Other methods may also be used to determine if the change in initial concentration is negligible. One method is to assume the change is negligible and use the resulting equilibrium concentrations to calculate the value of K_a (or K_b). If the calculated value is less than 5% different from the given value, the assumption made was acceptable; otherwise, the assumption should not be made.

Students should compare the terms endpoint and equivalence point. Students should identify the pH of a solution using indicators. Students should choose appropriate acid-base indicators given the pH at the equivalence point and a table of effective pH ranges for various acid-base indicators. Students could perform an experiment to determine the pH of various acids and bases using indicators.

Students could explain a titration curve involving a polybasic species with a strong acid (hydrochloric acid with sodium carbonate). Furthermore, they should explain the results of a titration graph involving a polyprotic species with a strong base (phosphoric acid with sodium hydroxide) and the pH at the equivalence point when strong acids are mixed with weak bases, and vice versa. Teachers might mention salt hydrolysis here to help explain titration curves, in particular when the pH at the equivalence point does not equal 7.

Content Knowledge: Redox & Electrochemistry

CK 4.1	*Learners are expected to ...*					
	describe the chemical changes that occur during redox reactions.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
		■				

Achievement Indicators

Learners who have achieved this outcome should be able to …

a define the following: oxidation, reduction, oxidizing agent, reducing agent, oxidation number, half-reaction equation, and an oxidation reduction (redox) reaction;

b identify the oxidation numbers of the atoms in molecules or ions using oxidation number rules;

c identify the species oxidized and reduced in a redox reaction;

d identify the oxidizing and reducing agents; and

e distinguish between oxidation-reduction reactions and other kinds of reactions.

Essential Graduation Competencies

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

ELABORATIONS

As an introduction, identify questions about oxidation and reduction to investigate or talk about. Begin by listing things students already know or think they know about electrochemistry. Topics might include the components of various types of batteries, what happens when iron corrodes, or how electroplating occurs.

Students should define the terms: oxidation-reduction, oxidizing agent, reducing agent, oxidation number, half-reaction equations, and an oxidation-reduction (redox) reaction. Using oxidation number rules, students should find the oxidation numbers of atoms in the molecules or ions. Teachers should provide examples of how Lewis structures can be used to identify oxidation numbers. Students could observe a zinc strip in a copper (II) sulfate solution, represented by the equation: $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$. Discussion might be initiated by stating that the zinc is said to undergo oxidation because its' oxidation state increases from 0 to +2, and the copper is said to undergo reduction because its oxidation state decreases from +2 to 0.

Students should identify electron transfer in half-reaction equations like $Zn \rightarrow Zn^{2+} + 2e^-$ and $Cu^2+ + 2e^- \rightarrow Cu$. Oxidation (loss of electrons) and reduction (gain of electrons) do not occur separately. Copper ions could not be reduced without a source of electrons, and zinc, when oxidized, needs another substance to take the electrons that are given up. The oxidizing agent, Cu^{2+}, is reduced, and Zn, the reducing agent, is oxidized in this oxidation-reduction reaction.

Other examples could be provided to allow students to identify the substances oxidized and reduced as well as the oxidizing and reducing agents. Students should perform lab experiments to observe a redox reaction, such as $AgNO_3$ and Cu. They could then write equations for the reaction, describe their observations, analyse the results, and identify the oxidizing and reducing agents. "OIL RIG" is a mnemonic device that relates to redox reactions: "Oxidation Involves Loss, Reduction Involves Gain." LEO (Loss Electrons Oxidation) the lion says GER (Gain Electron Reduction) is another common mnemonic device.

Given a group of equations, students should identify which are redox reactions and which are not redox. Students should differentiate between oxidation-reduction reactions and non-redox reactions by identifying changes in oxidation number. Students should assign oxidation numbers to the species undergoing chemical change from examples provided (see examples below).

- The lead storage cell in automobile batteries; the reaction is $\mathrm{Pb} + \mathrm{PbO_2} + 2\mathrm{H_2SO_4} \rightleftarrows 2\mathrm{PbSO_4} + 2\mathrm{H_2O}$
- The fuel cell used in a spacecraft uses the reaction between hydrogen and oxygen gases with graphite electrodes at a pressure of 50 atm and temperature of 250°C; the overall reaction which occurs in the presence of a catalysts is $2\mathrm{H_2} + \mathrm{O_2} \rightarrow 2\mathrm{H_2O}$.

Content Knowledge: Redox & Electrochemistry

CK 4.2	*Learners are expected to ...*					
	balance redox reactions in acidic, basic, and neutral solutions using the half reaction method.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
			■			

Achievement Indicators

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

a write and balance half reactions and net redox reactions using the half reaction method in neutral solutions; and

b write and balance half reactions and net redox reactions for complex situations involving acidic and basic solutions.

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

ELABORATIONS

Students should write balanced half-reactions followed by the overall reaction. The balanced equation for neutral conditions could be obtained by writing half-reactions and adding them. One or both equations might need to be multiplied by appropriate integers so that the number of electrons gained by the oxidizing agent equals the number lost by the reducing agent.

For example:
(1) $Au^{3+} + 3e^- \rightarrow Au$ (reduction half)
(2) $Zn \rightarrow Zn^{2+} + 2e^-$ (oxidation half)

Multiplying equation (1) by 2 and equation (2) by 3 gives the following half reactions:
(1) $2Au^{3+} + 6e^- \rightarrow 2Au$
(2) $3Zn \rightarrow 3Zn^{2+} + 6e^-$

Now that the number of electrons gained and lost are equivalent, the half reaction equations can be added to give the following net reaction:
$2Au^{3+} + 3Zn \rightarrow 2Au + 3Zn^{2+}$

Many redox reactions occur only in acidic or basic solutions. Acidic solutions have H^+ and H_2O available to take part in the reaction and must be used to assist in balancing the redox equation. Basic solutions have OH^- and H_2O available to take part in the reaction; similarly, they must also be used to assist in balancing the redox equation. It is not expected that students use the Oxidation Number Method for balancing redox equations. CK4.2

Students could perform a stoichiometric experiment involving a redox reaction. A redox titration would be appropriate and timely as it ties together the stoichiometry from Chemistry 521A and titration techniques from the Acids and Bases section of Chemistry 621A. The balanced redox equation could be given to the students or they could be asked to balance the equation using their newly acquired knowledge and understanding prior to performing stoichiometric calculations.

CONTENT KNOWLEDGE: REDOX & ELECTROCHEMISTRY

CK 4.3	*Learners are expected to ...*					
	analyse the functioning of electrochemical cells.					
	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
				■		

Achievement Indicators

Learners who have achieved this outcome should be able to …

a describe the components of an electrochemical cell: anode, cathode, anion, cation, salt bridge/porous cup, and external circuit;

b analyse an electrochemical cell to describe the reaction that occurs at the electrodes, the resulting electron flow, and ion migration;

c write balanced equations for reactions at the cathode, the anode, and overall reaction;

d illustrate the functioning of an electrochemical cell;

e describe an electrochemical cell using cell notation;

f measure cell potentials;

g understand the conditions used for standard reduction potential values;

h calculate the cell potential ($\Delta E°cell$) for an electrochemical cell; and

i identify whether oxidation-reduction reactions are spontaneous based on standard reduction potential.

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

Outcome CK4.3 is best addressed in a laboratory setting where a student can assemble, test, and analyse the functioning of electrochemical cells. Students should illustrate, define, and identify the following parts of an electrochemical cell: anode, cathode, anion, cation, salt bridge/porous cup, and internal and external circuit. Students should identify the flow of electrons in the external circuit, the migration of ions through the porous barrier or salt bridge, measure the cell potential, and calculate the theoretical cell potential.

Consider the following electrochemical cell.

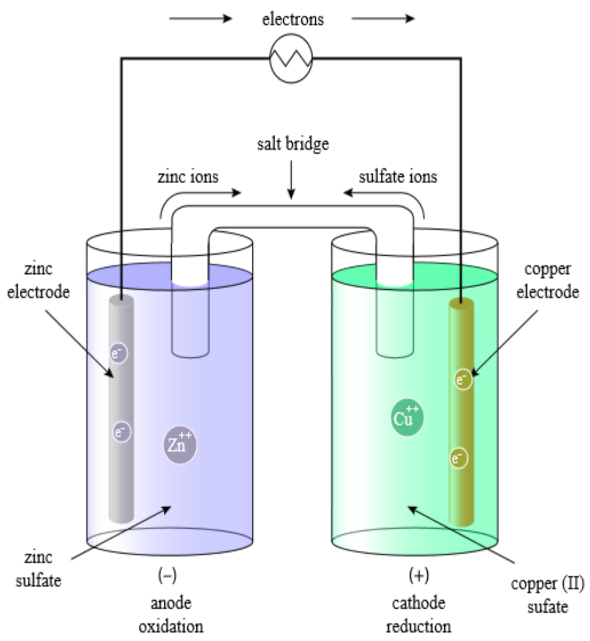


Figure 14. Electrochemical Cell

Anode ½ Reaction: $Zn_s \rightleftarrows Zn^{2+}_{aq} + 2e^-$ (Oxidation)
Cathode ½ Reaction: $Cu^{2+}_{aq} + 2e^- \rightleftarrows Cu_s$ (Reduction)
Overall Reaction: $Zn_s + Cu^{2+}_{aq} \rightleftarrows Zn^{2+} + Cu_s$
Cell Notation: $Zn_s \mid Zn^{2+}_{aq} \parallel Cu^{2+}_{aq} \mid Cu_s$

Students should be familiar with the standard conditions for reduction potentials as being Standard Atmospheric Temperature and Pressure (SATP) with concentrations of 1 mol/L based on the standard hydrogen half-cell. They should predict the voltage of electrochemical cells based on the relative location of the metals involved from a table of standard reduction potentials or table containing an activity series of metals.

Students should define a spontaneous reaction as one that produces a positive cell potential. Using the table of standard reduction potentials they should predict the spontaneity of redox reactions on the basis of calculated standard cell potential values, and the relative positions of half-reduction equations on a standard reduction potential table.

Students could write and balance oxidation-reduction reactions using half-reaction equations obtained from a standard reduction potential table. Students should understand that the scientific community has universally accepted the values for half-reaction potentials based on the $2H^+ + 2e^- \rightarrow H_2$ half-cell (ΔE^0_{cell}=0V) under standard conditions. Two manipulations are often required to obtain a balanced redox reaction. One of the reduction half-reactions must be reversed and since the number of electrons lost must equal the number gained, half-reactions must be multiplied by integers for electron balance. Students should know the value $E°_r$ is not changed when a half cell is multiplied by a factor; the standard reduction potential, $E°_r$, does not depend on how many times the reaction occurs. Consider the following electrochemical cell involving zinc and copper:

Cell Notation: $Zn_s \mid Zn^{2+}_{aq} \parallel Cu^{2+}_{aq} \mid Cu_s$

Students can obtain the standard reduction potentials from tables or charts, for example:
(1) $Cu^{2+} + 2e^- \rightarrow Cu$ $E°_r = 0.34V$
(2) $Zn^{2+} + 2e^- \rightarrow Zn$ $E°_r = -0.76V$

By reviewing the reduction potentials the reactions at the cathode and anode can be identified:
(1) $Cu^{2+} + 2e^- \rightarrow Cu$ $E°_r$ (cathode) = 0.34V (highest reduction potential - reduction occurs at cathode)
(2) $Zn \rightarrow Zn^{2+} + 2e^-$ $E°_r$ (anode) = -0.76V (lowest reduction potential - oxidation occurs at anode)

The potential difference (cell potential or voltage) can now be calculated as follows:
$\Delta E^o_{cell} = E^o_{r\,(cathode)} - E^o_{r\,(anode)}$
$\Delta E^o_{cell} = 0.34V - (-0.76V)$
$E^o_{cell} = 1.10$ V (the reaction is spontaneous)

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
Foundations of Scientific Literacy	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
Foundations of Scientific Literacy	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
Foundations of Scientific Literacy	Decisions and Perspectives *How should we apply science?*	• Learning to respect self and others • Controlling physical interactions • Collaborating with and listening to others	• Extending focus beyond self and immediate environment • Becoming aware of the benefits and responsibilities associated with science and technology • Becoming aware of personal perspectives related to science issues • Recognizing and demonstrating respect for different perspectives

Appendix A: The Scientific Continuum

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

Appendix B: Literacy Strategies that Support Science Learning

Literacy Strategies that Support Science Learning

Speaking and Listening

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

Reading and Viewing

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

Writing and Representing

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

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).

References

Council of Atlantic Ministers of Education and Training. (2015). Atlantic Canada Framework for Essential Graduation Competencies. Retrieved November 3, 2023, from https://www.ednet.ns.ca/files/curriculum/atlantic_canada_essential_grad_competencies.pdf

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

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

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

Durlak, J.A., Weissberg, R.P., Dymnicki, A., Taylor, R.D., & Schellinger, K.B. (2011). The impact of enhancing students' social and emotional learning: A meta-analysis of school-based universal interventions. Child Development, 82, 405-432.

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

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

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

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

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

Honouring the Truth, Reconciling for the Future: Summary of the Final Report of the Truth and Reconciliation Commission of Canada. Truth and Reconciliation Commission of Canada, 2015, www.trc.ca/assets/pdf/Honouring_the_Truth_Reconciling_for_the_Future_July_23_2015.pdf. PDF download.

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

ISO, (2012). Robots and robotic devices — Vocabulary. Retrieved July 29, 2019, from https://www.iso.org/obp/ui/#iso:std:iso:8373:ed-2:v1:en

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

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

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

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

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

References

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Srinivasan, M. (2019) SEL Everyday: Integrating Social and Emotional Learning with Instruction in Secondary Classrooms. W.W. Norton & Company.

References

“Standards for the 21st Century Learner to launch during AASL National Conference.” American Library Association. 2007. http://www.ala.org/ala/pressreleases2007/october2007/standards07.htm (Accessed 03 Nov, 2021) Collaborative for Academic, Social, and Emotional Learning (CASEL). (n.d.). Home - CASEL.

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

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

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

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

Weissberg, R.P. & Cascarino, J. (2013). Academic learning + social-emotional learning = national priority. Phi Delta Kappan, 95 (2), 8-13.

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

Wiglesworth, M., Lendrum, A., Oldfield, J., Scott, A., ten Bokkel, I., Tate, K., & Emery, C. (2016). The impact of trial stage, developer involvement and international transferability on universal social and emotional learning programme outcomes: A meta-analysis. Cambridge Journal of Education, 46, 347-376.

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