SECTION 1

MANITOBA FOUNDATIONS FOR SCIENTIFIC LITERACY

The Five Foundations

To develop scientifically literate students, Manitoba science curricula are built upon five foundations for scientific literacy (Figure 1) that have been adapted from the *Pan-Canadian Science Framework* to address the needs of Manitoba students. These include:

- Nature of Science and Technology
- Science, Technology, Society, and the Environment (STSE)
- Scientific and Technological Skills and Attitudes
- Essential Science Knowledge
- Unifying Concepts

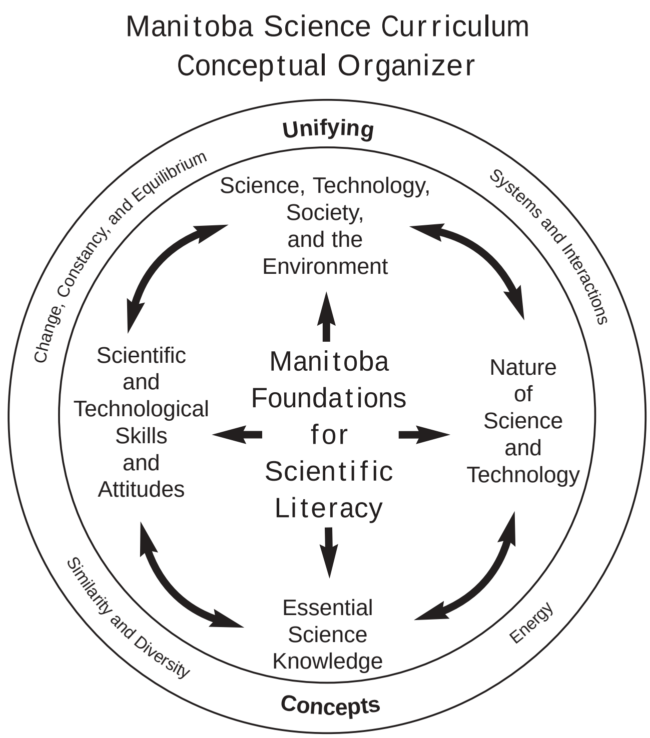

Figure 1: Manitoba Science Curriculum Conceptual Organizer

In the following pages, each foundation is described, representing the goals of science learning in Kindergarten to Senior 4. These foundations led to the development of the general learning outcomes contained in *Senior 3 Physics: A Foundation for Implementation* (2003).

Nature of Science and Technology

Students learn that science and technology are creative human activities with long histories in all cultures. Science is a way of learning about the universe. This learning stems from curiosity, creativity, imagination, intuition, exploration, observation, replication of experiments, interpretation of evidence, and debate over that evidence and its interpretations. Scientific activity involves predicting, interpreting, and explaining natural and human-made phenomena. Many historians, sociologists, and philosophers of science presently argue that there is no definable, set procedure for conducting a scientific investigation. Rather, they see science as driven by a combination of theoretical concerns, knowledge, experiments, and processes anchored in the physical world.

> Producing science knowledge is an intrinsically collective endeavour. There is no such thing as stand-alone science done in isolation. Scientists submit models and solutions for the assessment of their peers, who judge their logical, rational and experimental soundness through reference to the body of existing knowledge and modes of representation (Larochelle and Désautels, 1992).

Scientific theories are being tested, modified, and refined continually as new knowledge and theories supersede existing knowledge bases. Scientific debate, both on new observations and on hypotheses that challenge accepted knowledge, involves many participants with diverse backgrounds. This highly complex interplay, which has occurred throughout history, is animated by theoretical discussions; experimentation; social, cultural, economic, and political influences; personal biases; and the need for peer recognition and acceptance. Students will realize that while some of our understandings about how the world works are due to revolutionary scientific developments, many of our understandings result from the steady and gradual accumulation of knowledge. History demonstrates, however, that great advances in scientific thought have completely uprooted certain disciplines, transplanting practitioners and theoreticians alike into an entirely new set of guiding assumptions. Such *scientific revolutions*, as discussed by Thomas S. Kuhn in his influential *The Structure of Scientific Revolutions* (Kuhn, 1962), constitute exemplars that can energize the science teaching enterprise—particularly in physics education.

Technology results mainly from proposing solutions to problems arising from human attempts to adapt to the external environment. Technology may be regarded as "… a tool or machine; a process, system, environment, epistemology, and ethic; the systematic application of knowledge, materials, tools, and skills to extend human capabilities…" (Manitoba Education and Training, *Technology As a Foundation Skill Area: A Journey Toward Information Technology Literacy*, 1998). "Technology" refers to much more than the knowledge and skills related to computers and their applications. Technology is based on the knowledge of concepts and skills from other disciplines (including science), and is the application of this knowledge to meet an identified need or to solve a problem using materials, energy, and tools (including computers). Technology also has an influence on processes and systems, on society, and on the ways people think, perceive, and define their world.

Senior 3 Physics is designed to emphasize both the distinctions and relationships between science and technology. Figure 2 illustrates how science and technology differ in purpose, procedure, and product, while at the same time relate to each other.

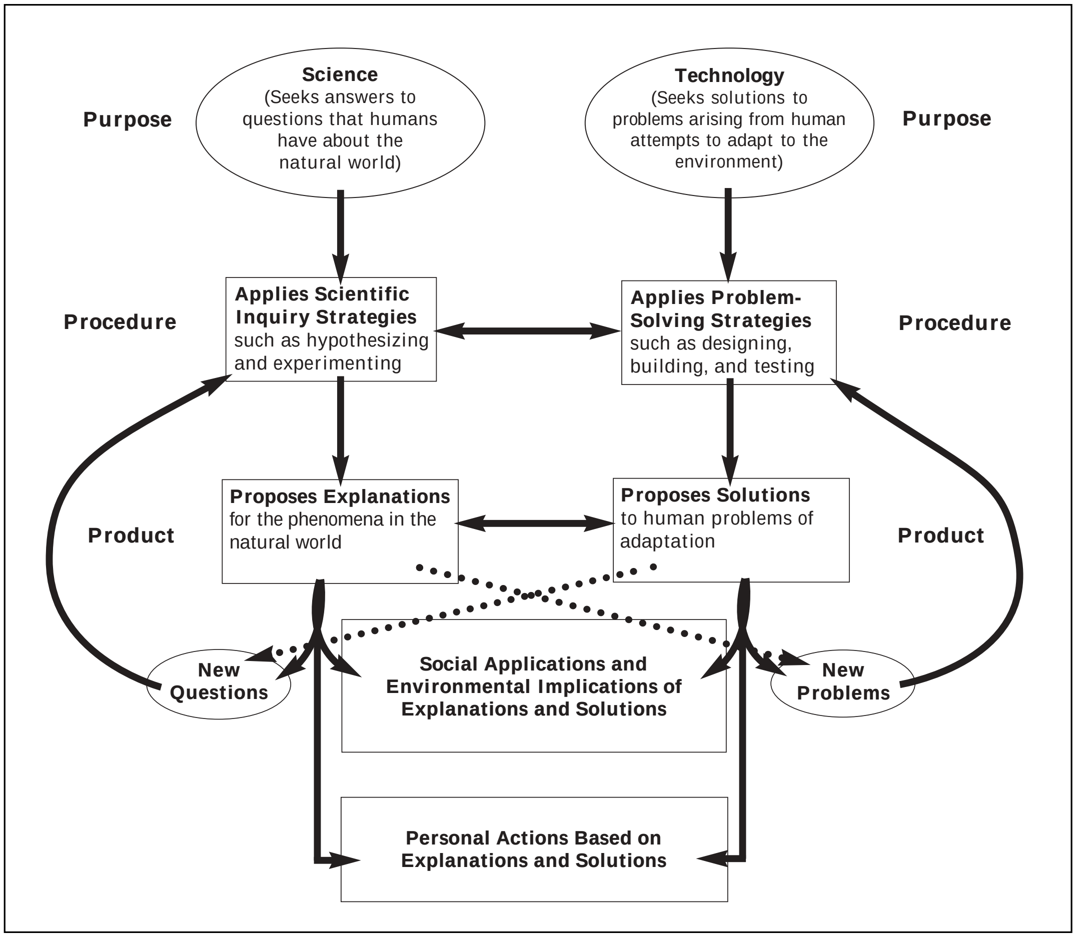

Figure 2: Science and Technology: Their Nature and Interrelationships*

* Adapted from Bybee, Rodger W. et al., *Science and Technology Education for the Elementary Years: Frameworks for Curriculum and Instruction*. Copyright © 1989 The NETWORK Inc.

The following General Learning Outcomes (GLOs) have been developed to further define expectations related to this foundation area (for a complete listing of Science GLOs, see Appendix 7).

Nature of Science and Technology General Learning Outcomes

As a result of their Senior Years science education, students will

A1. recognize both the power and limitations of science as a way of answering questions about the world and explaining natural phenomena

A2. recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop

A3. distinguish critically between science and technology in terms of their respective contexts, goals, methods, products, and values

A4. identify and appreciate contributions made by women and men from many societies and cultural backgrounds that have increased our understanding of the world and brought about technological innovations

A5. recognize that science and technology interact with and advance one another

Science, Technology, Society, and the Environment (STSE)

Understanding the complex interrelationships among STSE is an essential component of fostering increased scientific literacy. By studying the historical context, students come to appreciate ways in which cultural and intellectual traditions have influenced the questions and methodologies of science, and how science, in turn, has influenced the wider world of ideas.

Today, most scientists work in industry, where projects are more often driven by societal and environmental needs than by pure research. Many technological solutions have evoked complex social and environmental issues. Students recognize the potential of scientific literacy to inform and empower decision making of individuals, communities, and society as a whole.

Scientific knowledge is necessary, but not sufficient, for understanding the relationships among science, technology, society, and the environment. To understand these relationships fully, it is essential that students consider the values related to science, technology, society, and the environment.

As a component of achieving scientific literacy, students must also develop an appreciation for the importance of sustainable development. Sustainable development is a decision-making model that considers the needs of both present and future generations, and integrates and balances the impact of economic activities, the environment, and the health and well-being of the community (see Figure 3). Educators are encouraged to consult *Education for a Sustainable Future* (Manitoba Education and Training, 2000), which outlines ways of incorporating precepts, principles, and practices to foster appropriate learning environments that would help direct students toward a sustainable future. The document can be accessed online at:

<http://www.edu.gov.mb.ca/ks4/docs/support/future/sustaineducation.pdf>.

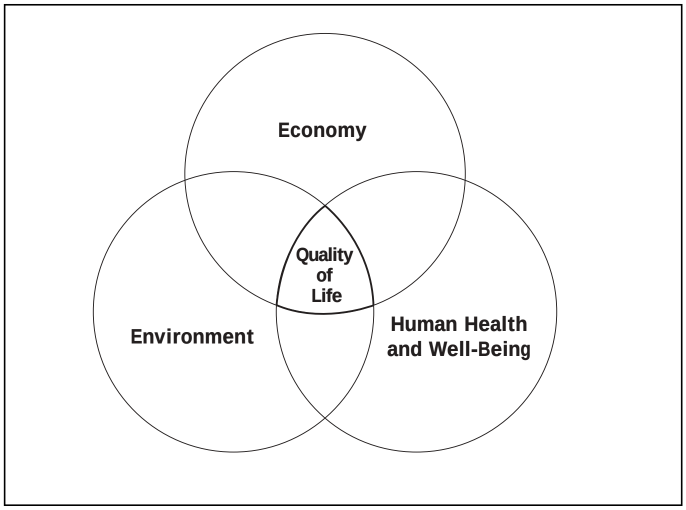

Figure 3: Sustainable Development

Sustainable human health and well-being is characterized by people coexisting harmoniously within local, national, and global communities, and with nature. A sustainable society is one that is physically, psychologically, spiritually, and socially healthy. The well-being of individuals, families, and communities is of considerable importance.

A **sustainable environment** is one in which the life-sustaining processes and natural resources of the Earth are conserved and regenerated.

A **sustainable economy** is one that provides equitable access to resources and opportunities. It is characterized by development decisions, policies, and practices that respect cultural realities and differences, and do not exhaust the Earth's resources. A sustainable economy is evident when decisions, policies, and practices are carried out to minimize their impact on the Earth's resources and to maximize the regeneration of the natural environment.

Decisions or changes related to any one of the three components—human health and well-being, the environment, or the economy—have a significant impact on the other two components and, consequently, on our quality of life. Decision making must take into account all three components to ensure an equitable, reasonable, and sustainable quality of life for all.

Sustainable Development, Social Responsibility, and Equity

Sustainable development supports principles of social responsibility and equity. Williams (1994) believes that the concept of equity is essential to the attainment of sustainability. This includes equity among nations, within nations, between humans and other species, as well as between present and future generations.

Sustainable development is, at the same time, a decision-making process, a way of thinking, a philosophy, and an ethic. Compromise is an important idea that underlies the decision-making process within a sustainable development approach. In order to achieve the necessary balance among human health and well-being, the environment, and the economy, some compromises will be necessary.

> There can be no greater contribution or more essential element to long-term environmental strategies leading to sustainable development that respects the environment … than the education of future generations in matters relating to the environment (UNESCO, 1988).
>
> Public awareness and understanding of the concept of sustainable development and its practices are essential. If we are to change our way of life we must equip present and future generations with the knowledge and training to put sustainable development into effect (Sustainability Manitoba, 1994).

As students advance from grade to grade, they identify STSE interrelationships and apply decision-making skills in increasingly demanding contexts, as outlined in the following ways:

- **complexity of understanding**—from simple, concrete ideas to abstract ideas; from limited knowledge of science to more in-depth and broader knowledge of science and the world;
- **applications in context**—from contexts that are local and personal to those that are societal and global;
- **consideration of variables and perspectives**—from one or two that are simple to many that are complex;
- **critical judgement**—from simple right or wrong assessments to complex evaluations; and
- **decision making**—from decisions based on limited knowledge, made with the teacher's guidance, to decisions based on extensive research that are made independently and involve personal judgement.

This foundation area has led to the development of the following GLOs in *Senior 3 Physics: A Foundation for Implementation*.

Science, Technology, Society, and the Environment (STSE) General Learning Outcomes

As a result of their Senior Years science education, students will

B1. describe scientific and technological developments—past and present—and appreciate their impact on individuals, societies, and the environment, both locally and globally

B2. recognize that scientific and technological endeavours have been and continue to be influenced by human needs and the societal context of the time

B3. identify the factors that affect health, and explain the relationships among personal habits, lifestyle choices, and human health, both individual and social

B4. demonstrate a knowledge of and personal consideration for a range of possible science- and technology-related interests, hobbies, and careers

B5. identify and demonstrate actions that promote a sustainable environment, society, and economy, both locally and globally

Scientific and Technological Skills and Attitudes

A science education that strives for developing scientific literacy must engage students in answering questions, solving problems, and making decisions. These processes are referred to as scientific inquiry, technological problem solving (the design process), and decision making (see Figure 4). While the skills and attitudes involved in these processes are not unique to science, they play an important role in the development of scientific understandings and in the application of science and technology to new situations.

	Scientific Inquiry	**Technological Problem Solving (Design Process)**	**Decision Making**
Purpose:	Satisfying curiosity about events and phenomena in the natural world.	Coping with everyday life, practices, and human needs.	Identifying different views or perspectives based on varying information.
Procedure:	What do we know? What do we want to know?	How can we do it? Will it work?	What are the alternatives or consequences? Which choice is best at this time?
Product:	Knowledge about events and phenomena in the natural world.	An effective and efficient way to accomplish a task or meet a need.	A defensible decision in a particular circumstance.

	Scientific Question	**Technological Problem**	**STSE Issue**
Example:	Why does my coffee cool so quickly? *An Answer:* Heat energy is transferred by conduction, convection, and radiation to the surrounding environment.	How can I keep my coffee hot? *A Solution:* A foam cup will keep liquids warm for a long time. So will an insulated cup.	Should we use foam cups or ceramic mugs for our meeting? *A Decision:* Since we must use disposable cups for the meeting, a biodegradable type will be chosen.

Figure 4: Processes for Science Education*

*Adapted with permission of the Minister of Education, Province of Alberta, Canada, 1999.

Each of these ***processes*** is described on the following page. ***Attitudes***, an important element of each process, are also examined, and are treated as indicators along the pathway of student achievement. Hence, attitudes are to be modelled by teachers and students, but are not formally assessed in the same manner as other specific learning outcomes.

Scientific Inquiry

Scientific inquiry is a way of learning about the universe. It involves posing questions and searching for explanations of phenomena. Although no single "scientific method" exists, students require certain skills to participate in science-related experiences using a variety of appropriate methods.

Skills such as questioning, observing, inferring, predicting, measuring, hypothesizing, classifying, designing experiments, and collecting, analyzing, and interpreting data are fundamental to scientific inquiry—as are attitudes such as curiosity, skepticism, and creativity. These skills are often represented as a cycle. This cycle involves posing questions, generating possible explanations, and collecting and analyzing evidence to determine which of these explanations is most useful and accurate in accounting for the phenomena under investigation. New questions may arise to reignite the cycle. It must be noted, however, that many scientific inquiries (past and present) do not necessarily follow a set sequence of steps, nor do they always start at the "beginning" of the cycle; scientists can be creative and responsive to scientific challenges as they arise.

Technological Problem Solving

Technological problem solving seeks solutions to problems arising from human attempts to adapt to or change the environment. In Kindergarten to Grade 8 science, students have been developing these skills using a cycle of steps called the design process. This design process includes the proposing, creating, and testing of prototypes, products, and techniques in an attempt to reach an optimal solution to a given problem. Feedback and evaluation are built into this cycle. In Senior Years science, these technological problem-solving skills are incorporated into a decision-making process.

STSE Issues and Decision Making

Students, as individuals and global citizens, are required to make decisions. Increasingly, the types of issues they face demand an ability to apply scientific and technological knowledge, processes, and products to the decisions they make related to STSE. The decision-making process involves a series of steps, which may include:

- clarification of the issue;
- critical evaluation of all available research;
- generating possible courses of action;
- making a thoughtful decision;
- examining the impact of the decision; and
- reflecting on the process.

Students should be actively involved in decision-making situations as they progress through their science education. Not only are decision-making situations important in their own right, but they also provide a relevant context for engaging in scientific inquiry, problem solving, and the study of STSE relationships (see Figure 5).

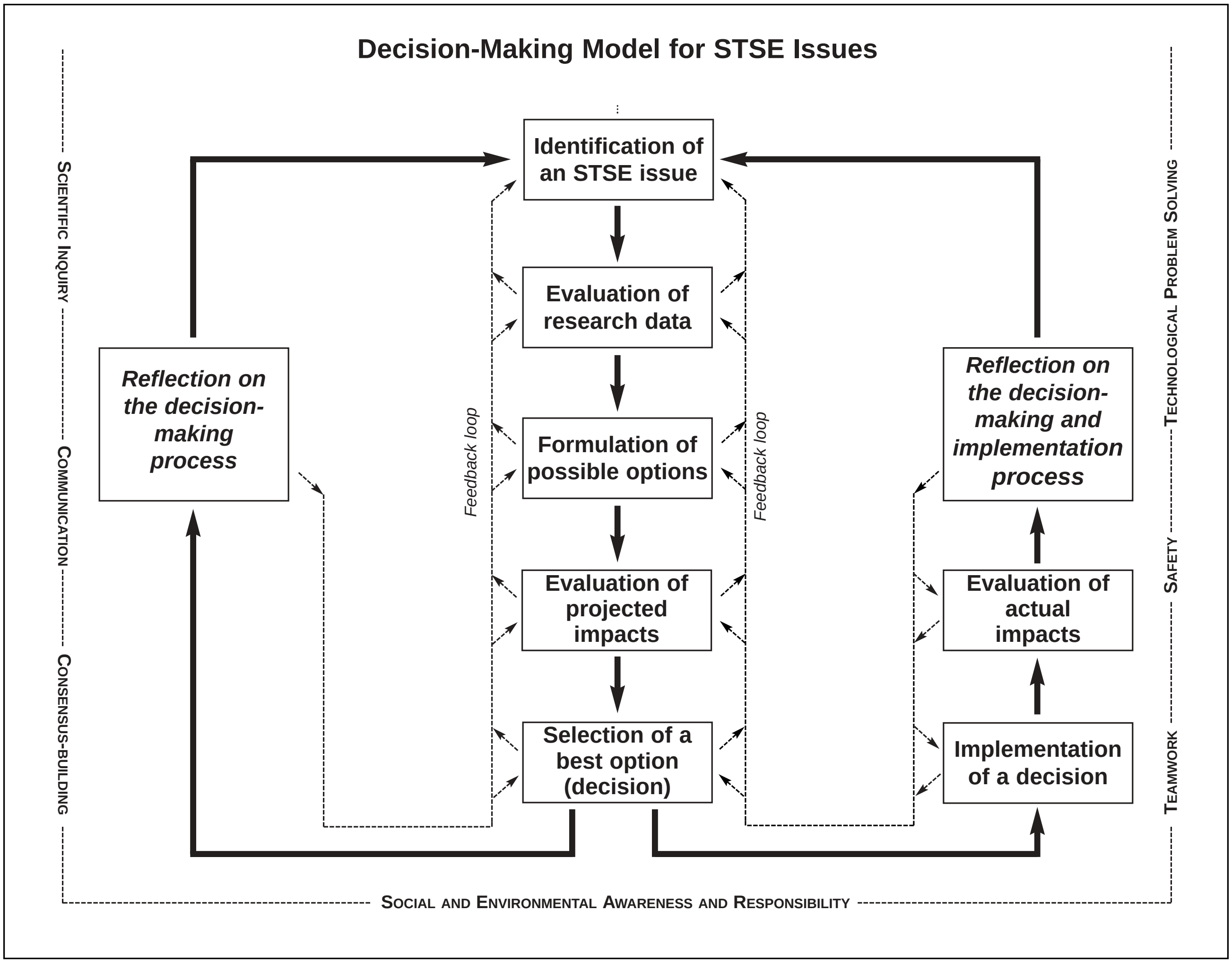

Figure 5: Decision-Making Model for STSE Issues

Attitudes

Attitudes refer to generalized aspects of behaviour that are modelled for students. Attitudes are not acquired in the same way as skills and knowledge. They cannot be observed at any particular moment, but are evidenced by regular, unprompted manifestations over time. Development of attitudes is a lifelong process that involves the home, the school, the community, and society at large. The development of positive attitudes plays an important role in students' growth, affecting their intellectual development and creating a readiness for responsible application of what they learn.

The following **General Learning Outcomes** (GLOs) have been developed to further define expectations related to this foundation area, and provide the basis for the set of Skills and Attitudes that are identified as unique to Senior 3 Physics.

Scientific and Technological Skills and Attitudes General Learning Outcomes

As a result of their Senior Years science education, students will

C1. recognize safety symbols and practices related to scientific and technological activities and to their daily lives, and apply this knowledge in appropriate situations

C2. demonstrate appropriate scientific inquiry skills when seeking answers to questions

C3. demonstrate appropriate problem-solving skills when seeking solutions to technological challenges

C4. demonstrate appropriate critical thinking and decision-making skills when choosing a course of action based on scientific and technological information

C5. demonstrate curiosity, skepticism, creativity, open-mindedness, accuracy, precision, honesty, and persistence, and appreciate their importance as scientific and technological habits of mind

C6. employ effective communication skills and use information technology to gather and share scientific and technological ideas and data

C7. work cooperatively and value the ideas and contributions of others while carrying out scientific and technological activities

C8. evaluate, from a scientific perspective, information and ideas encountered during investigations and in daily life

Essential Science Knowledge

The subject matter of science includes theories, models, concepts, and principles that are essential to an understanding of life science, physical science, and Earth and space science. Content is a vehicle for essential learnings (Drake, 1993), and it will be increasingly important for students of physics to make interdisciplinary connections among the following.

Life Sciences: This involves the study of the growth and interactions of life forms within their environment in ways that reflect their uniqueness, diversity, genetic continuity, and changing nature. Life science includes the study of organisms (including humans and cells), ecosystems, biodiversity, biochemistry, and biotechnology.

PHYSICAL SCIENCES: Primarily associated with chemistry and physics, the physical sciences deal with matter, energy, and forces. Matter has structure, and interactions exist among its components. Energy links matter to gravitational, electromagnetic, and nuclear forces of the universe. The laws of conservation of mass and energy, momentum, and charge are addressed by physical science.

GEOSCIENCES AND THE SPACE SCIENCES: These studies provide students with local, global, and universal perspectives. Earth exhibits form, structure, and patterns of change, as does our surrounding solar system and the physical universe beyond. Earth and space science includes fields of study such as geology, hydrology, meteorology, and astronomy.

The following GLOs have been developed to further define expectations related to this foundation area.

Essential Science Knowledge General Learning Outcomes

As a result of their Senior Years science education, students will

D1. understand essential life structures and processes pertaining to a wide variety of organisms, including humans

D2. understand various biotic and abiotic components of ecosystems, as well as their interaction and interdependence within ecosystems and within the biosphere as a whole

D3. understand the properties and structures of matter as well as various common manifestations and applications of the actions and interactions of matter

D4. understand how stability, motion, forces, and energy transfers and transformations play a role in a wide range of natural and constructed contexts

D5. understand the composition of the Earth’s atmosphere, hydrosphere, and lithosphere, as well as the processes involved within and among them

D6. understand the composition of the universe, the interactions within it, and the implications of humankind’s continued attempts to understand and explore it

The Unifying Concepts

An effective way to create linkages within and among science disciplines is to use unifying concepts—the key ideas that underlie and integrate all science knowledge and extend into areas such as mathematics and social studies. Unifying concepts help students construct a more holistic, systems-related understanding of science and its role in society.

The following four unifying concepts were used in the development of *Senior 3 Physics: A Foundation for Implementation*.

Similarity and Diversity

The concepts of similarity and diversity provide tools for organizing our experiences with the world. Beginning with informal experiences, students learn to recognize attributes of materials, organisms, and events that help to make useful distinctions between and among them. Over time, students adopt accepted procedures and protocols for describing and classifying objects, organisms, and events they encounter, thus enabling them to share ideas with others and to reflect on their own experiences.

Systems and Interactions

An important part of understanding and interpreting the world is the ability to think about the whole in terms of its parts and, alternately, about parts in terms of how they relate to one another and to the whole. A system is a collection of components that interact with one another so that the overall effect is often different from that of the individual parts, even when these are considered together. Students will study both natural and technological systems.

Change, Constancy, and Equilibrium

The concepts of constancy and change underlie most understandings of the natural and technological world. Through observations, students learn that some characteristics of living things, materials, and systems remain constant over time, whereas others change. Through formal and informal studies, students develop an understanding of the processes and conditions in which change, constancy, and equilibrium take place.

Energy

The concept of energy provides a conceptual understanding that brings together many aspects of natural phenomena, materials, and the processes of change. Energy, whether transmitted or transformed, is the driving force of both movement and change. Students learn to describe energy in terms of its effects and, over time, develop a concept of energy as something inherent within the interactions of materials, the processes of life, and the functions of systems.

The following GLOs have been developed to further define expectations related to this foundation area.

Unifying Concepts General Learning Outcomes

As a result of their Senior Years science education, students will

E1. describe and appreciate the similarity and diversity of forms, functions, and patterns within the natural and constructed world

E2. describe and appreciate how the natural and constructed world is made up of systems and how interactions take place within and among these systems

E3. recognize that characteristics of materials and systems can remain constant or change over time, and describe the conditions and processes involved

E4. recognize that energy, whether transmitted or transformed, is the driving force of both movement and change, and is inherent within materials and in the interactions among them

Kindergarten to Senior 2 Topic Chart

The following table provides a quick reference to the different thematic clusters from Kindergarten to Senior 2. This allows teachers to examine, at a glance, students' previous exposure to scientific knowledge in different areas.

	Cluster 0	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Kindergarten	Overall Skills and Attitudes	Trees	Colours	Paper	—
Grade 1		Characteristics and Needs of Living Things	The Senses	Characteristics of Objects and Materials	Daily and Seasonal Changes
Grade 2		Growth and Changes in Animals	Properties of Solids, Liquids, and Gases	Position and Motion	Air and Water in the Environment
Grade 3		Growth and Changes in Plants	Materials and Structures	Forces that Attract or Repel	Soils in the Environment
Grade 4		Habitats and Communities	Light	Sound	Rocks, Minerals, and Erosion
Grade 5		Maintaining a Healthy Body	Properties of and Changes in Substances	Forces and Simple Machines	Weather
Grade 6		Diversity of Living Things	Flight	Electricity	Exploring the Solar System
Grade 7		Interactions within Ecosystems	Particle Theory of Matter	Forces and Structures	Earth's Crust
Grade 8		Cells and Systems	Optics	Fluids	Water Systems
Senior 1		Reproduction	Atoms and Elements	Nature of Electricity	Exploring the Universe
Senior 2		Dynamics of Ecosystems	Chemistry in Action	In Motion	Weather Dynamics

Figure 6: Kindergarten to Senior 2 Topic Chart