

SCIENTIFIC LITERACY

The Foundations for Scientific Literacy

Kindergarten to Grade 4 Science: A Foundation for Implementation is designed in accordance with the vision for scientific literacy articulated in the *Common Framework of Science Learning Outcomes K to 12: Pan-Canadian Protocol for Collaboration on School Curriculum* (1997) (hereafter referred to as the *Pan-Canadian Science Framework*).

The *Pan-Canadian Science Framework*

is guided by the vision that all Canadian students, regardless of gender or cultural background, will have an opportunity to develop scientific literacy. Scientific literacy is an evolving combination of the science-related attitudes, skills, and knowledge. Students need to develop inquiry, problem-solving, and decision-making abilities, to become lifelong learners, and to maintain a sense of wonder about the world around them.

Diverse learning experiences based on the [Pan-Canadian] framework will provide students with many opportunities to explore, analyze, evaluate, synthesize, appreciate, and understand the interrelationships among science, technology, society, and the environment that will affect their personal lives, careers, and their future. (p. 4)

To develop scientific literacy, science learning experiences must incorporate the essential aspects of science and its related applications. These essential aspects, the foundations for scientific literacy, have been adapted from the *Pan-Canadian Science Framework* to address the needs of Manitoba students. Manitoba science curricula are built upon the following five foundations for scientific literacy:

- A. Nature of Science and Technology
- B. Science, Technology, Society, and Environment (STSE)
- C. Scientific and Technological Skills and Attitudes
- D. Essential Science Knowledge
- E. Unifying Concepts

For more background on each of these foundation areas, consult *Kindergarten to Grade 4 Science: Manitoba Curriculum Framework of Outcomes* (1999) (hereafter referred to as *K–4 Science Manitoba Framework*).

Manitoba's vision for scientific literacy, as reflected in the five foundation areas, represents a paradigm shift in science education also evident across North America and Western Europe. The chart on the following page highlights some areas in which there are changing emphases.

CHANGING EMPHASES*

The *National Science Education Standards* envision change throughout the system. The science content standards [or student learning outcomes] encompass the following changes in emphases:

LESS EMPHASIS ON

Knowing scientific facts and information

Studying subject matter disciplines (physical, life, earth sciences) for their own sake

Separating science knowledge and science process

Covering many science topics

Implementing inquiry as a set of processes

MORE EMPHASIS ON

Understanding scientific concepts and developing abilities of inquiry

Learning subject matter disciplines in the context of inquiry, technology, science in personal and social perspectives, and history and nature of science

Integrating all aspects of science content

Studying a few fundamental science concepts

Implementing inquiry as instructional strategies, abilities, and ideas to be learned

CHANGING EMPHASES TO PROMOTE INQUIRY

LESS EMPHASIS ON

Activities that demonstrate and verify science content

Investigations confined to one class period

Process skills out of context

Emphasis on individual process skills such as observation or inference

Getting an answer

Science as exploration and experiment

Providing answers to questions about science content

Individuals and groups of students analyzing and synthesizing data without defending a conclusion

Doing few investigations in order to leave time to cover large amounts of content

Concluding inquiries with the result of the experiment

Management of materials and equipment

Private communication of student ideas and conclusions to teacher

MORE EMPHASIS ON

Activities that investigate and analyze science questions

Investigations over extended periods of time

Process skills in context

Using multiple process skills—manipulation, cognitive, procedural

Using evidence and strategies for developing or revising an explanation

Science as argument and explanation

Communicating science explanations

Groups of students often analyzing and synthesizing data after defending conclusions

Doing more investigations in order to develop understanding, ability, values of inquiry and knowledge of science content

Applying the results of experiments to scientific arguments and explanations

Management of ideas and information

Public communication of student ideas and work to classmates

* Source: *National Science Education Standards*, p. 18. © 1996 by the National Academy of Sciences. Reproduced with permission of the National Academy Press.

Achieving Scientific Literacy through Student Learning Outcomes

General student learning outcomes (GLOs) for Manitoba, based on the five foundation areas, define overall expectations for scientific literacy from Kindergarten to Senior 4. Appendix A: General Learning Outcomes includes a complete list of GLOs, excerpted from *K–4 Science Manitoba Framework*. Specific student learning outcomes (SLOs) that further define expectations for student achievement at each grade are also included in this document.

Specific student learning outcomes for Kindergarten to Grade 4 science are arranged in clusters. Clusters 1 to 4 are thematic groupings that generally correspond to disciplinary distinctions within science, including life science, physical science, and Earth and space science. (Note: Kindergarten has only three thematic clusters.) Specific student learning outcomes included in Cluster 0 address the overall science skills and attitudes students are expected to achieve. For a full listing of Cluster 0 student learning outcomes, consult *K–4 Science Manitoba Framework* or the Overall Skills and Attitudes Chart Kindergarten to Grade 4 science included with this document.

Cluster Titles

	K	Grade 1	Grade 2	Grade 3	Grade 4
Cluster 0	Overall Skills and Attitudes (to be integrated into Clusters 1 to 4)				
Cluster 1	Trees	Characteristics and Needs of Living Things	Growth and Changes in Animals	Growth and Changes in Plants	Habitats and Communities
Cluster 2	Colours	The Senses	Properties of Solids, Liquids, and Gases	Materials and Structures	Light
Cluster 3	Paper	Characteristics of Objects and Materials	Position and Motion	Forces that Attract or Repel	Sound
Cluster 4	N/A	Daily and Seasonal Changes	Air and Water in the Environment	Soils in the Environment	Rocks, Minerals, and Erosion

Scientific and Technological Skills and Attitudes

Science education, with scientific literacy as its goal, must engage students in scientific inquiry, technological problem solving (design process), and decision making. These skills, behaviours, and attitudes are essential for the development of scientific understanding and the application of science and technology to new situations. Cluster 0 from *K–4 Science Manitoba Framework* identifies student learning outcomes related to scientific inquiry and technological problem solving (design process), as well as those that apply to both processes. For some educators, this way of conceptualizing science will be new. Yet, the increasing importance of technology in daily life and the need for critical problem-solving skills underscore the importance of integrating basic science concepts with skills and attitudes related to scientific inquiry and the design process.

The following figure, adapted from Alberta Education, illustrates some differences and similarities between scientific inquiry and the design process in purpose, procedure, and product. As teachers plan for the integration of student learning outcomes from Cluster 0: Overall Skills and Attitudes they will become more familiar with these two distinct processes as well as the overlapping skills involved.

Processes for Science Education*

	Scientific Inquiry	Design Process (Technological Problem Solving)
Purpose	satisfying curiosity about events and phenomena in the natural world	coping with everyday life practices, and human needs
Procedure	What do we know? What do we want to know?	How can we do it? Will it work?
Product	knowledge about events and phenomena in the natural world	an effective and efficient way to accomplish a task or meet a need
	Scientific Question	Technological Design Problem
Example	Why does my coffee cool so quickly? <i>An answer:</i> Heat energy is transferred by conduction, convection, and radiation.	How can I keep my coffee hot? <i>An answer:</i> One solution is to develop a styrofoam cup that will keep liquids warm for a long time.

* Source: Science-Technology—STSE Chart. Adapted with permission of the Minister of Education, Province of Alberta, Canada, 1999.

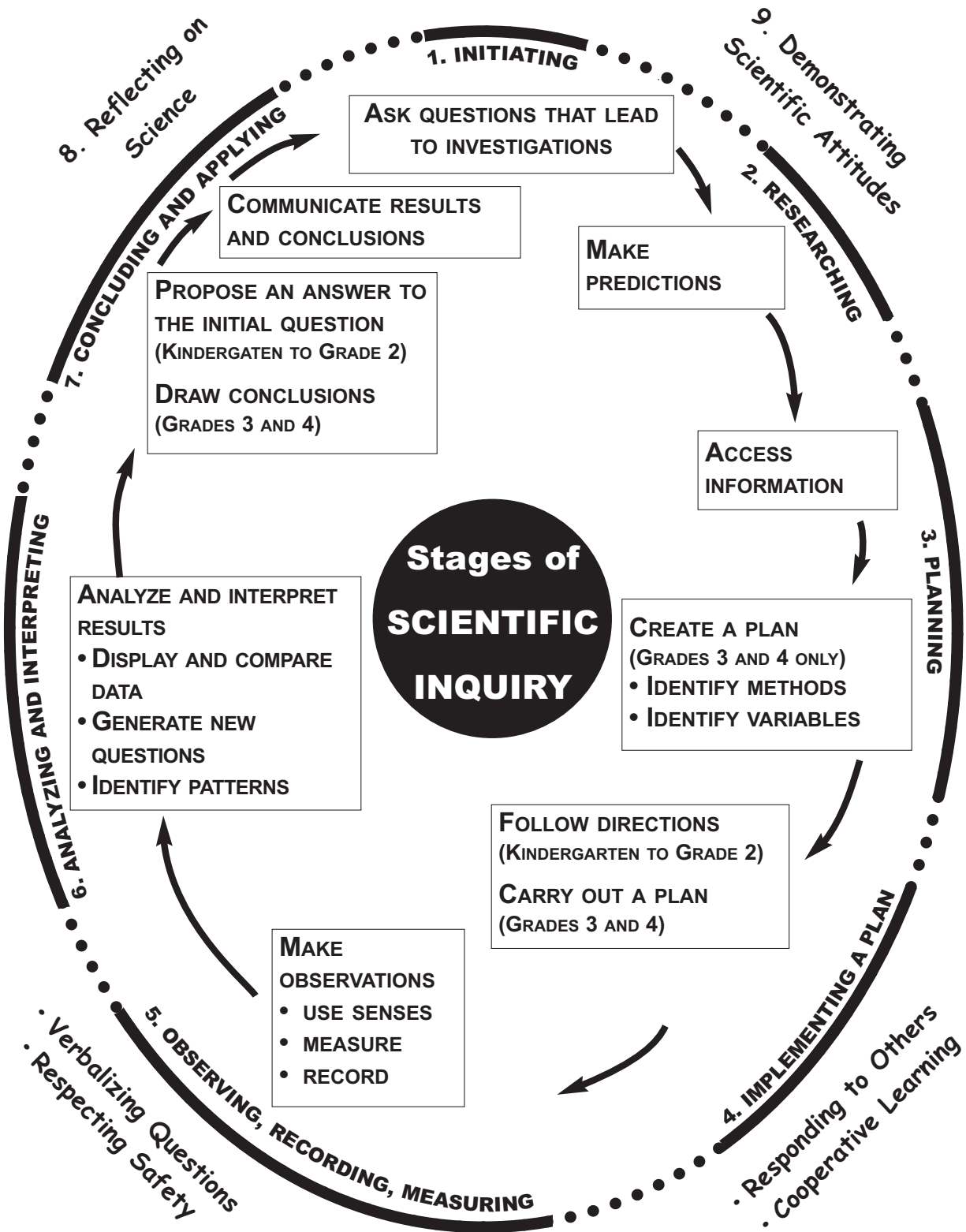
As shown in the accompanying poster, Overall Skills and Attitude Chart Kindergarten to Grade 4 Science, the specific student learning outcomes in Cluster 0 are identified as applying to scientific inquiry, the design process, or both (see example). The scientific inquiry elements are included in black type on a white box on the left. The design process elements are clearly identified by the use of white type on a black box on the right. Learning outcomes related to both processes are located in a horizontal box below the left and right hand boxes. All specific student learning outcomes appear in a numbered and lettered sequence, e.g., 1a., 1b., 1c., 2a., 2b., etc.

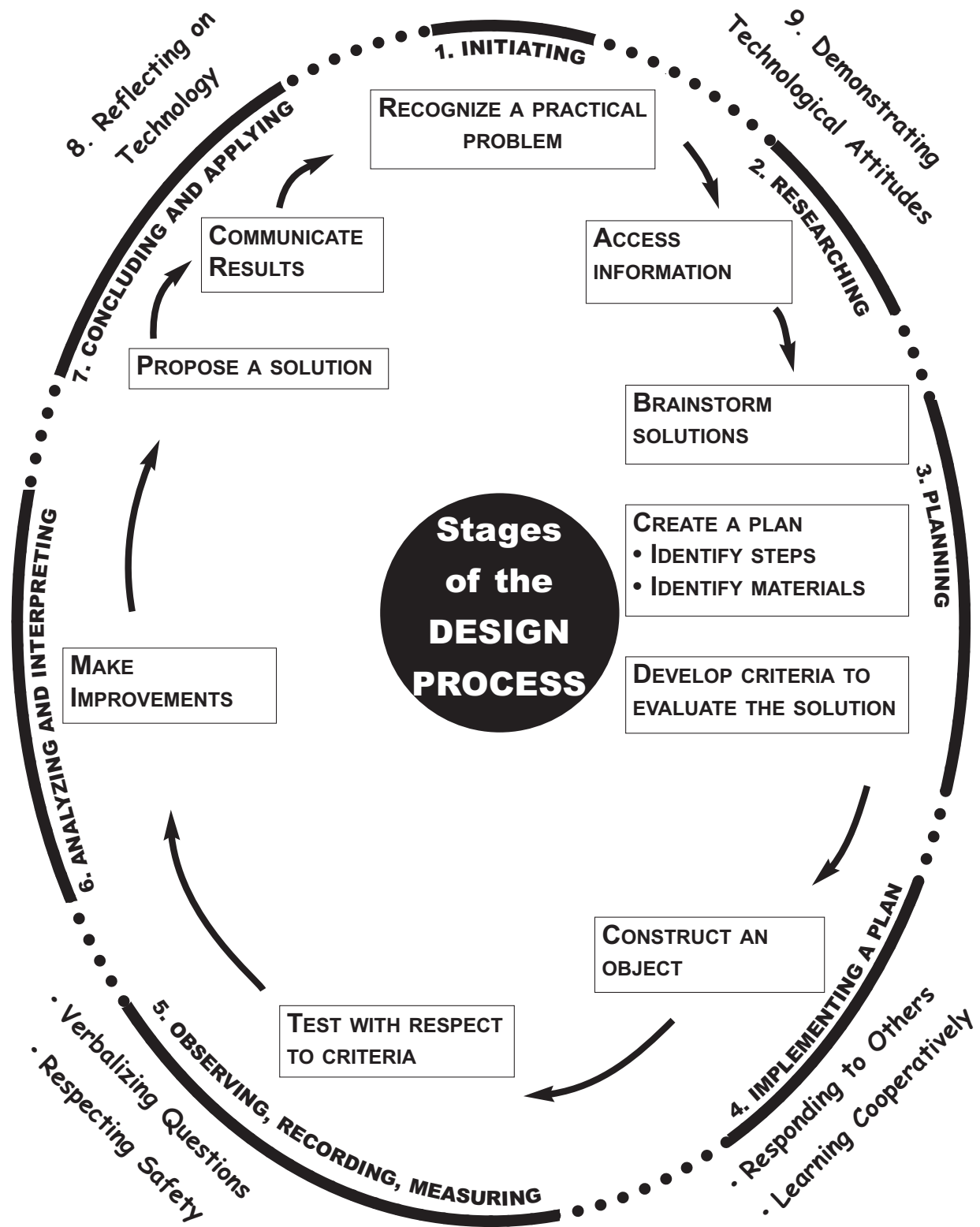
Grade 2	
Scientific Inquiry	Design Process
<p>1a. Ask questions that lead to investigations of living things, objects, and events in the immediate environment. (ELA 1.2.4, 3.1.2, 3.1.3; Math SP-I.1.2) GLO: A1, C2, C5</p> <p>1b. Make predictions based on observed patterns or on collected data. (ELA 1.1.1, 1.2.1) GLO: A1, C2</p>	<p>1c. Identify practical problems to solve in the immediate environment. GLO: C3</p>
<p>2a. Access information using a variety of sources. <i>Examples: elders, simple chapter books, concept books, CD-ROMs, Internet...</i> (ELA 1.1.2, 3.2.2 Math SP-II.1.2; TFS 2.1.1) GLO: C6</p> <p>2b. Match information to research needs. (ELA 3.2.3, 3.3.3) GLO: C6, C8</p>	

These specific student learning outcomes are further organized into the following nine categories:

1. Initiating
2. Researching
3. Planning
4. Implementing a Plan
5. Observing, Measuring, Recording
6. Analyzing and Interpreting
7. Concluding and Applying
8. Reflecting on Science and Technology
9. Demonstrating Scientific and Technological Attitudes

The two graphics on the following pages illustrate the stages of scientific inquiry and the design process. Detailed descriptions of each process follow the graphics.





Scientific Inquiry

As indicated in the graphic on page 14, scientific inquiry generally proceeds according to a sequence of stages, although there will be differences in the order and number of stages the students undertake. With repetition and experience, students will become aware of the logical underpinnings of scientific inquiry and develop familiarity and fluency with the requisite skills and attitudes. While all grades follow the general stages of scientific inquiry, there are significant differences in expectations of students across the grades. In Kindergarten to Grade 2, the teacher manages the plan for the scientific inquiry and controls the variables. At these grades, the purpose of the scientific inquiry is to propose one answer to the initial question. By Grades 3 and 4, students work as a class to plan their own experiments and identify and control variables, carry out the experiments in small groups, and draw conclusions related to the initial question.

Stages of Scientific Inquiry

The stages of the scientific inquiry are discussed in detail below. It should be noted that these stages are general guidelines and every scientific inquiry may not address all stages or stages in the exact order provided here.

- **Asking Questions That Lead to Investigations** — Scientific inquiry begins with a child’s curiosity to explore his/her world. Active inquiry starts by asking questions that lead to “investigations of living things, objects, and events in the immediate environment” (*Kindergarten to Grade 4 Science Framework*, 3.26).
- **Making Predictions** — Using prior knowledge, observed patterns, and collected data, students develop ideas to predict possible answers to questions.
- **Accessing Information** — Accessing information is directly linked to SLO 3.2 for *K–4 ELA, Select and Process*. Using a variety of print, non-print, electronic, and human resources, students access information and match it to their inquiry or research needs.
- **Creating a Plan** — This stage of scientific inquiry begins at Grade 3. From Kindergarten to Grade 2, the teacher is responsible for planning scientific inquiry and controlling the variables. At Grades 3 and 4, students work with the class to create a plan to answer a given question and identify variables that need to be controlled. A variable is an object or quantity that can change. For example, learning outcome 3-1-04 expects students to *conduct experiments to determine conditions needed for healthy plant growth*. The conditions listed in the “include” portion of the learning outcome identify variables to be controlled — *light, water, air, space, warmth, growing medium, nutrient*. To test the impact of sunlight on plant growth, students need to ensure that all other variables such as water, air, space, warmth, growing medium, etc., are exactly the same for all plants. By controlling these variables, any changes in the plant can be attributed to different amounts of sunlight.
- **Following Directions (Kindergarten to Grade 2)/Carrying Out a Plan (Grades 3 and 4)** — At this inquiry stage, Kindergarten to Grade 2 students implement a plan, following specific directions. Students in Grades 3 and 4 carry out a plan following and describing a sequence of steps. These steps link directly to SLO 3.1.2 *K–4 ELA, Create and Follow a Plan*. Throughout this stage of scientific inquiry, students are involved in group collaboration, communication, and safety procedures and rules.

- **Making Observations** — During the observation process, students are involved in perceiving characteristics and changes using their senses. Measurement enables students to find the dimensions or quantity of an object and the duration of an event. At this stage, students develop skills in estimating size, mass, length, volume, and time and in selecting and using appropriate measuring devices. Observations can be recorded in a variety of ways. The language arts of *representing* and *writing* allow students to record data using tables, charts, pictures, simple labelled diagrams, flowcharts, sentences, and simple reports.
- **Displaying and Comparing Data** — Students can use pictures or labelled diagrams, charts, graphs, etc. to display their data. These means of organization facilitate data comparison. Through this comparison, students can generate new questions related to the data that may lead to further scientific inquiry. They may also begin to see patterns in the data that help them answer questions or draw conclusions.

This inquiry stage is directly linked to mathematical skills. To facilitate this interdisciplinary integration, references are made to learning outcomes from *Kindergarten to Grade 4 Mathematics: Manitoba Curriculum Framework of Outcomes and Grade 3 Standards* (1996).

- **Proposing an Answer/Drawing Conclusions** — From Kindergarten to Grade 2, students propose an answer to an initial question. This answer comes directly from the scientific inquiry itself. It is not dependent on students' applying prior scientific knowledge. For example, in the scientific inquiry related to learning outcome *K-2-05, Predict and describe changes in colour that result from the mixing of primary colours and from mixing a primary colour with white or black*, students are asked to determine which colours result when two or more primary colours are combined. The expected answers may include "red and blue make purple" or "yellow and blue make green." These statements are based directly on observations made in the inquiry itself.

At Grades 3 and 4, students begin to draw conclusions. The conclusions are based on the data collected from the scientific inquiry, as well as on data collected from other inquiries; patterns seen in data; and prior scientific knowledge or understandings. These conclusions are broader statements that can be applied beyond the boundaries of a specific scientific inquiry.

For example, in the scientific inquiry related to learning outcome *3-1-04, Conduct experiments to determine conditions needed for healthy plant growth*, students conduct a scientific inquiry to answer the question: "What do you think plants need to survive?" The subsequent analysis of their inquiry results, combined with their understanding of the needs of living things from Grade 1, Cluster 1, gives students an answer specifically related to the plants in their experiment. Students are then expected to generalize these findings to all plants in the form of a conclusion. For example: All plants require light, water, air, space, warmth, and nutrients in order to grow and remain healthy.

- **Communicating Results** — "In writing, speaking, and representing, students construct meaning in order to communicate with others" (*Kindergarten to Grade 4 English Language Arts: A Foundation for Implementation*, p. 10). Through photo essays, videos, sketchbooks, flow charts, oral presentations, illustrated reports, or demonstrations, students can communicate the findings and procedures of their scientific inquiry. They can share their thoughts related to the scientific inquiry process through group discussion.

Materials Required for Scientific Inquiry

From Kindergarten to Grade 4, the materials required for explorations and investigations are generally household items, classroom supplies, and recycled objects. At times, students use tools to enhance their observations. A listing of tools for each grade can be found in Cluster 0: Overall Skills and Attitudes.

Safety Considerations

Throughout Kindergarten to Grade 4, the primary responsibility for safety in science belongs to teachers and other school personnel. It is important, however, for students to become aware of the importance of safety measures regarding themselves, others, and the environment. It is essential to instill in every student's mind that safety must be a principal consideration in planning and carrying out scientific experiments, investigations, and explorations. This attitude is a critical component of the scientific culture of students who will become responsible citizens of the future.

Assessment

Students' application of the steps of the scientific inquiry process involves the acquisition of knowledge, skills, and behaviours. Like all other areas of the curriculum, scientific inquiry skills and attitudes should be assessed in relation to the prescribed student learning outcomes. (See page 5 for a general discussion on assessment.) Teachers need to identify and become familiar with Cluster 0 grade-level learning outcomes that focus on skills specific to scientific inquiry. These skills are difficult to assess in a paper and pencil format. They are best assessed through observations, interviews, and tasks that involve students in actively exploring, investigating, and experimenting.

Design Process

As indicated in the graphic on page 15, the design process consists of a series of sequenced stages. Many of these skills and attitudes in the design process will be new to Early Years students. Repetition and discussion will encourage familiarity with the stages and a broader understanding of technological problem solving.

While all grades follow the general stages of the design process shown above, there are significant differences in expectations of students across the grades. In Kindergarten to Grade 2, brainstorming and planning are generally done with the class. By Grade 3, students are brainstorming and planning in small groups. By Grade 4, they are able to carry out these activities independently. The level of sophistication of evaluation criteria for the finished product also changes over the grades. In Kindergarten to Grade 1 the criteria are limited to those related directly to function. In Grade 4, other considerations such as materials and cost take on greater significance.

Stages of the Design Process

The stages of the design process are discussed in detail below. It should be noted that these stages are general guidelines and every design task may not address all stages, or stages in the exact order provided here.

- **Recognizing a Practical Problem** — Recognizing a practical problem initiates the design process. For example, the practical problem for outcome 2.3.14, *Use the design process to construct a vehicle with wheels and axles that meet given criteria*, could be presented in the following manner:

Design and construct a vehicle with 4 wheels and 2 axles that can travel 2 metres across a surface by a push and include a container holding 15 marbles.

Teachers may want to limit materials to

- cardboard
- a selection of specified materials for wheels (e.g., plastic lids, film canisters, spools, cardboard circles, etc.)
- pencils, dowelling, and wooden skewers
- a selection of joining materials (e.g., glue, string, rubber bands, clips, staples, tape, etc.)

Limiting materials provides structure and guidance to the Early Years student who may be overwhelmed by the potential choices.

- **Researching/Accessing Information** — Gathering information is an integral part of the entire design process. Information is gathered in a number of ways from a variety of resources. The teacher’s task is to decide
 - what information will be needed
 - which learning resources are appropriate
 - what information is required to meet the student learning outcomes
 - what information-gathering skills and activities are appropriate to the task
 - what strategies are required for developing research skills

Gathering information requires individual and class discussion as well as effective teacher questioning that activates students’ prior knowledge and experiences and allows for the acquisition and integration of new knowledge. Class discussions will provide teachers with opportunities to identify students’ misconceptions and the need for further research.

- **Developing Evaluation Criteria** — Criteria must be specific enough to limit the scope of impractical solutions and ensure success, but also open-ended enough to allow originality and creativity. The criteria should be generated with student input. The teacher may specify criteria related to the specific learning outcome and available materials, but students can add other criteria. Student-developed criteria often relate to the real-world, such as, “the vehicle must contain a section for the driver and a steering wheel.”

Other categories of criteria that can be included are

- Aesthetics: For some solutions, aesthetics are a factor. The criterion of being “visually appealing” can be included, with student input as to the descriptors (e.g., colour, scale, etc.).
- Cost: By assigning a monetary value to materials or processes, cost efficiency can be addressed.
- Environmental Impacts: Criteria that focus on environmental impacts, sustainability, the effect of the design solution on the environment, and the STSE component of the science curriculum can be addressed.

- **Brainstorming Solutions** — Brainstorming first involves generating many ideas without evaluating them. It involves teacher questioning strategies to encourage fluency, flexibility, and the elaboration of ideas. Brainstorming assists students in the development of critical thinking skills, group communication, and interaction. The design team or student group will discuss the various ideas generated during brainstorming. An idea, which might be a combination of several ideas, is selected as the best possible solution to meet the need or problem.
- **Creating a Plan** — At this stage, the group decides on materials to implement their solution. The planned product should be sketched and labelled prior to construction. The selection of materials and the design will demonstrate students’ understanding of science knowledge and skills associated with the task. As a student gains experience in the design process, she or he will readily sketch the planned solution before making it. For younger students, the making will often come first, with a picture of the design following the construction. Teachers should encourage the visualization of the solution and model the sketching/labelling step.
- **Constructing an Object** — Making the design gives students experience in identifying the properties of materials and their uses. It provides opportunities to apply science knowledge and skills that have been developed through the particular science cluster.

For example, the design problem associated with specific learning outcomes 2.3.14, requires students to have experience with the workings and construction of wheels and axles (student learning outcomes 2.3.11-13) prior to constructing the solution. This may involve the use of structured activities using commercially available construction kits or building sets. The construction stage may involve the generation and revision of ideas and the identification of the need for further research. This could result in a solution that differs from the original design.

- **Testing with Respect to Evaluation Criteria** — Once the design problem has been solved, students must test the finished product or solution against the evaluation criteria specified earlier. The students self-evaluate and peer-evaluate their products and processes. They suggest ideas for improvement of the product. They reflect on the group interaction and the various stages of the design process.
- **Making Improvements** — From testing and evaluating the final product, students will be able to consider their design solutions in order to
 - make modifications
 - list modifications
 - revise the design sketch to reflect modifications
- **Proposing a Solution** — The design process concludes with the proposal of a solution that has been tested with respect to the evaluation criteria and that reflects improvements based on students’ analyses. New problems may also be identified, leading to the need for new product development.
- **Communicating Results** — “In writing, speaking, and representing, students construct meaning in order to communicate with others” (*K-4 ELA Foundation*, p. 10). Through photo essays, videos, design sketchbooks, flow charts, oral presentations, illustrated reports, or demonstrations, students can communicate the products and the procedures of their design process. It is important for students to share their thoughts related to the design process through group discussion.

Materials Required for the Design Process

Materials for a design task include recycled and everyday materials as well as construction kits. All have a place in the design process. When students first implement the design process in the science classroom, materials that are readily available, easily accessible, and familiar to students provide a good starting point.

Construction kits assist students in developing skills with tools and materials. Kits can be used as a medium for modelling or for open-ended exploration, prior to a specific design process learning experience.

For many design tasks, recycled materials such as newspapers, plastic drink bottles, string, boxes, etc., are sufficient. Supplemental items such as tape, glue sticks, straws, scissors, etc., will be needed as well. The use of recycled materials addresses the Science, Technology, Society, and the Environment (STSE) component of the curriculum.

It is important that students become familiar with the characteristics and properties of the materials they are using. Through open-ended exploration and discussion about materials, students gain knowledge about structural qualities. For certain design tasks, it is recommended that the materials be limited. This encourages students to explore and gain experience in the use and properties of specific materials and techniques by focussing their thinking.

At times, some tools will be required for constructing the solution/product. However, with the inclusion of design technology tasks in Early Years, many techniques have been adopted with young students in mind. For example, the use of materials such as cardboard triangles to join two pieces of wood replaces the need for hammers and nails.

Safety Considerations

The use of tools within the Early Years classroom raises safety concerns. As the teacher or school acquires specific tools for use in the design process, attention to the age of the students is important. Some suppliers who provide tools for the design technology component of the curriculum design these tools with the young user in mind. Low temperature glue guns, small bench hooks, mitre boxes, and safety goggles are a few such items. If cutting wood is required, it is important that students use hacksaws designed for the Early Years classroom, rather than bringing saws from home.

There are several methods to ensure safety in the classroom during the design process:

- Teach tool use. Demonstrate and have students practise safe use of the tools prior to beginning the task.
- Generate safety rules for the classroom, with the students developing the criteria whenever possible.
- Organize
 - the students (groupings, supervision, responsibilities)
 - the materials (storage, responsibilities)
 - the tools and equipment (storage, work area, student/teacher tools, supervision)
 - the design process display area
- Arrange the classroom for access to resources and equipment with safety in mind.

Assessment

Student learning outcomes for the design process, like all other areas of the curriculum, should be assessed for the acquisition of knowledge, skills, and behaviours. (See page 5 for a general discussion on assessment.) Teachers need to identify and become familiar with the grade-specific student learning outcomes in Cluster 0 that relate to the design process. Frequently, student learning can be assessed through teacher observation and questioning of students. Assessment should be based on the demonstration of learning that has taken place throughout the design process. Similarly, the solution should not be evaluated on whether it is right or wrong, but rather on the degree of its effectiveness in addressing the original problem.

Because of the sequential and recursive nature of the design process, student self-assessment and peer assessment should be ongoing. The design process also provides opportunities for formative assessment so that teachers can plan for the next stage of instruction and learning.

In the evaluation stage of the design process, assessment should focus on the positive aspects of the solution. Through the use of probing and open-ended questions, the teacher can elicit further thinking on the part of the student, as well as receive an indication about the student's level of achievement related to the learning outcomes. Design books, journals, and photo essays can provide records of each stage of the design process and assist in the assessment of student learning.