General Learning Outcome C

Scientific and Technological Skills and Attitudes

GLO C

Demonstrate appropriate inquiry, problem-solving, and decision-making skills and attitudes for exploring scientific and/or technological issues and problems.

Overview

General Learning Outcome C (GLO C) will be treated as *three* complementary components:

- Scientific Inquiry
- Design Process (Technological Solutions)
- Science, Technology, Society, and Environment (STSE) Issues and Decision Making

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, for the purposes here, as *scientific inquiry*, the *design process*, and *decision making*. 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.

Specific Learning Outcomes

SLO C1: Demonstrate appropriate scientific inquiry skills, attitudes, and practices when seeking answers to questions.

SLO C2: Demonstrate appropriate technological problem-solving skills and attitudes when seeking solutions to challenges and problems related to human needs.

SLO C3: Demonstrate appropriate critical thinking and decision-making skills and attitudes when choosing a course of action based on scientific and technological information.

SLO C4: Employ effective communication skills and use a variety of resources to gather and share scientific and technological ideas and data.

SLO C5: Work cooperatively with others and value their ideas and contributions.

General Learning Outcome C

Students will…

Demonstrate appropriate inquiry, problem-solving, and decision-making skills and attitudes for exploring scientific and/or technological issues and problems.

Specific Learning Outcomes

SLO C1: Demonstrate appropriate scientific inquiry skills, attitudes, and practices when seeking answers to questions.

SLO C4: Employ effective communication skills and use a variety of resources to gather and share scientific and technological ideas and data.

SLO C5: Work cooperatively with others and value their ideas and contributions.

Suggestions for Instruction

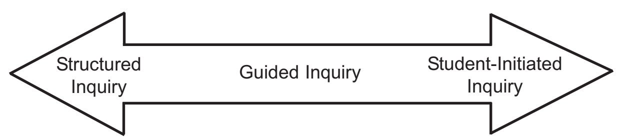
Scientific Inquiry

Scientific inquiry is an effective means of constructing knowledge and teaching the processes of science. Embedding teaching strategies within an overall inquiry-based pedagogy can enhance student performance and attitudes about science. Students become actively engaged in the learning process when given opportunities to hypothesize and investigate. Students are personally able to construct their own knowledge by posing questions, planning investigations, conducting their own experiments, and analyzing and communicating their findings. Also, students have opportunities to progress from concrete to abstract ideas, rethink their hypotheses, and retry experiments and problems (Jarrett; NRC, *National Science Education Standards*).

Inquiry must be developed in context and with connections to meaningful content. Building on relevant and accurate knowledge, teachers guide students in the logical development and integration of ideas. Scientific inquiry will allow students to gain skill in the practice of the methodology of science, including the development of hypotheses, theories, metaphors, laws, empirical and mathematical analysis, experimental and analytical design, observation, objectivity and perception, peer review, criticism, and consensus building. Scientific inquiry improves critical-thinking skills, including those related to deduction, induction, intuition, causality, association, and probability, as students investigate phenomena and construct meaning from data and observations.

Inquiry-based teaching often occurs on a continuum, with strategies and activities appropriate for a particular situation. At one end of the continuum is *structured inquiry*, where students engage in highly structured hands-on activities following precise instructions. In the middle of the continuum is *guided inquiry*, where students may assume responsibility for determining the procedure for an investigation, but the teacher chooses the question to be investigated. At the far end of the continuum is *student-initiated inquiry*, in which students generate their own questions and investigations. Student-initiated inquiry provides opportunities for students to exemplify thinking and behaving in scientific ways to solve personally and socially important problems. Students focus on all aspects of inquiry, designing and exploring an investigation in accordance with sound science practices.

A Proposed Continuum for Inquiry-Based Teaching

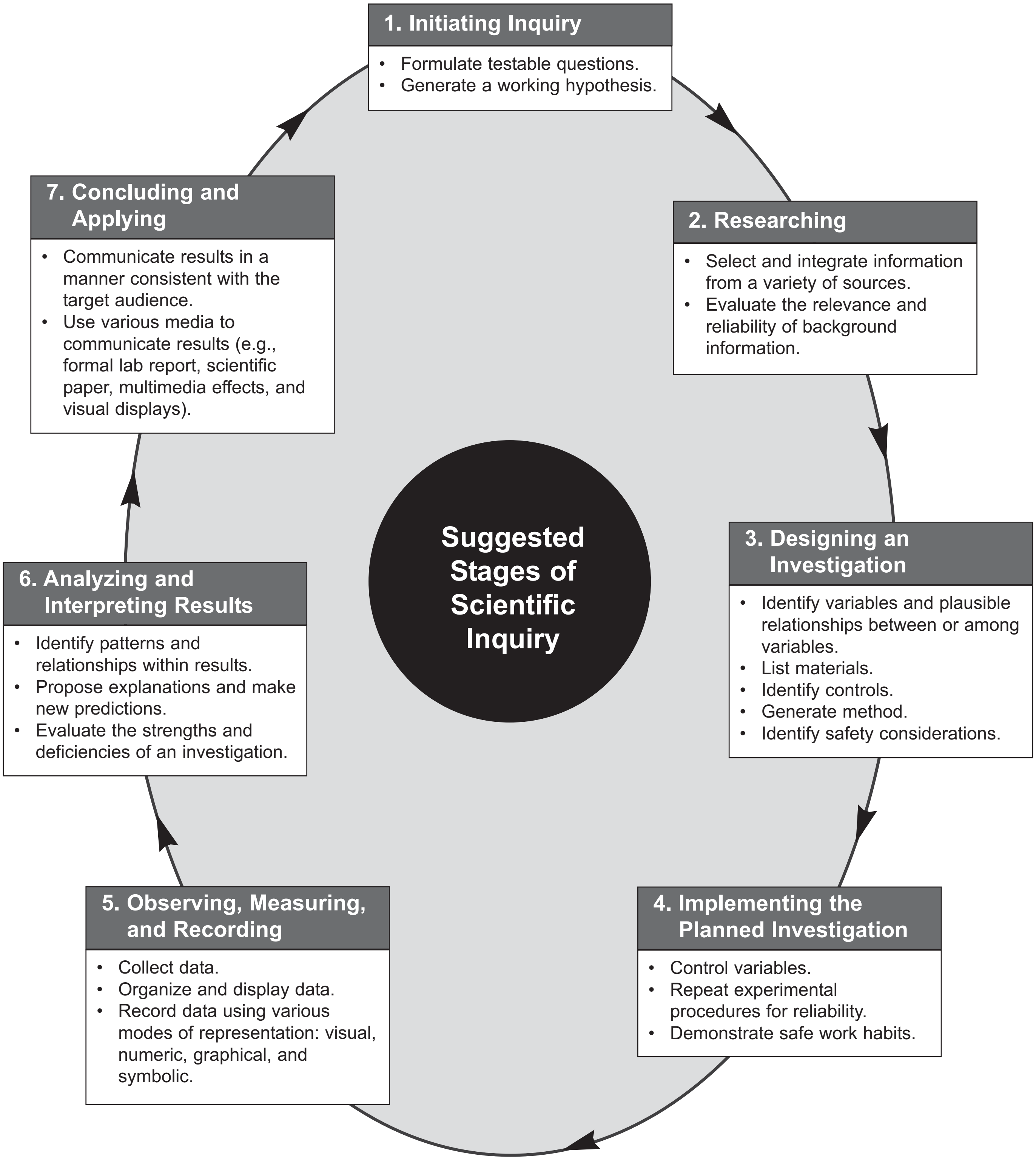


For students to develop into critical thinkers, they need to experience the freedom and responsibility of directing and focusing their own inquiries. (Strategies to move from pre-designed to student-designed laboratories are outlined in *SYSTH* 4.10-4.13.)

The Stages of Scientific Inquiry are illustrated on the following page.

Suggestions for Instruction

Stages of Scientific Inquiry



Suggestions for Instruction

Activating

Entry-Level Knowledge

- Throughout Kindergarten to Senior 2, students develop the scientific inquiry process.
- Senior 3 students have already developed scientific inquiry skills to allow them to propose testable questions and develop a hypothesis/prediction. Students locate, evaluate, and summarize relevant information from a variety of sources. They plan and carry out procedures, including the identification and treatment of materials, variables, controls, methods, and safety considerations. Students work cooperatively to collect, organize, and display data. They interpret patterns and explain relationships, forming conclusions. Students also develop key attitudes, an initial awareness of the nature of science, and other skills related to research, communication, the use of information technology, and cooperative learning.

Prior Knowledge Activities

- Learning activities and strategies such as the following allow teachers and students to activate prior knowledge, recognize misconceptions, and relate new information to prior experiences. In scientific inquiry, students must link personal science theories with generally accepted concepts of the science community. Discussion will allow an evaluation of this understanding, which may lead to the formation of questions and hypotheses.

  Examples of Strategies (See Appendix 2):

  Activities to activate prior knowledge include
  — Anticipation Guide
  — Discrepant Event
  — Drawing/Illustration of Concept
  — Knowledge Chart
  — KWL
  — LINK
  — Listen-Draw-Pair-Share
  — Rotational Cooperative Graffiti

The Stages of Scientific Inquiry: A Suggested Continuum

The stages of scientific inquiry (as illustrated diagrammatically on the previous page) are *general guidelines only*. They may not all be used as components in every scientific inquiry, nor do they occur in the same order in every situation. It is important for students to realize, through experiencing diversity, that no one specifiable "scientific method" is appropriate for investigating the natural world in all situations. It is a lingering, pervasive myth that science proceeds toward uncovering the "truths" of nature through its unique processes of inquiry, and that it is eminently successful at doing so.

1. **Initiating Inquiry**

   The general method of scientific inquiry often begins with a question, which is raised while observing relationships among natural phenomena. If there is no known answer to the question posed, then one or more plausible hypotheses or explanations can be tested by means of a scientific experiment to answer the question. The success of a scientific law, theory, or model is determined by its accuracy in predicting natural phenomena. As experiments are repeated and redesigned, scientists continually refine the existing prevailing scientific theories that govern their interpretation of data and observation, and construct refined models to match experimental results and to make better predictions about the behaviour of natural phenomena. For instance, if a theory cannot successfully make predictions or generate novel facts about phenomena, then holding on to it must be questioned.

   The inquiry process is especially relevant to students when they formulate their own questions. A good testable question will enhance students' ability to make predictions (e.g., a *working hypothesis*), create a plan, conduct fair tests, and make relevant observations and conclusions. Teachers may support this process with prompting and probing questions, helping students to define, focus, and delimit questions and problems to facilitate practical investigations.

Suggestions for Instruction

- **Formulate Testable Questions**

  A good, but simplified, testable question will often take the form of "How does ____ affect ____?" It will focus testing on only one factor (*Example*: "What is the effect of sunlight on the growth of plants?" instead of "What affects the growth of plants?").

  Example of a Testable Question:

  — *What is the effect of the application of heat on the viscosity of a fluid?*

  The above question includes the cause (the application of heat) and the effect (viscosity of a fluid). These two portions of the testable question are called variables. *Variables* are factors that can affect an event or process in some way. The *independent variable* is the **one** variable we choose to change. The *dependent variable* changes as a result of, or in response to, the change in the independent variable.

  Sometimes placing the variables in the following manner helps to identify each portion:

  ____________ depends on ______________
  dependent variable **independent variable**

  If we were to apply this approach to the testable question above, we might say:

  The viscosity of a fluid depends on the application of heat.
  dependent variable **independent variable**

  Example of Strategy:

  — Concept Relationship Frame—to examine associations between variables (*SYSTH* 11.20, 11.35)

- **Generate a Working Hypothesis**

  A *hypothesis* is a suggested answer of how one variable affects the other. The hypothesis should describe the relationship between the independent and dependent variables. Often it follows an *if-then* pattern:

  If the amount of heat added increases (**independent variable)**, then the viscosity will decrease (**dependent variable)**.

  Examples of Strategies (See Appendices 2 and 6):

  Activities to generate testable questions and generate a working hypothesis include

  — Brainstorming—Class/Group Discussion
  — Discrepant Event
  — KWL
  — Listen-Think-Pair-Share
  — Research and Debate
  — Rotational Cooperative Graffiti
  — Roundtable

2. **Researching**

   The research portion of scientific inquiry may take place at various stages during scientific inquiry.

   - **Select and Integrate Information from a Variety of Sources**
     It is important that students select and integrate information from a variety of sources, compiling and organizing information using appropriate formats and treatments.
   - **Evaluate Relevance and Reliability of Background Information**
     Students identify and apply criteria for evaluating evidence and sources of information, examining the reliability, bias, and usefulness of information gathered. Students then summarize and record the information in a variety of forms, including paraphrasing, quoting relevant facts and opinions, and referencing.

     Examples of Sources:

     — **Print**
       – texts
       – newspaper articles
       – journals
       – magazines

     — **Electronic**
       – Internet
       – videos
       – CD-ROMs
       – television

     — **Community**
       – resource people

Suggestions for Instruction

Examples of Strategies (see Appendices 4 and 5):
- — Article Analysis Frames
- — Case Studies
- — Concept Mapping
- — Fact-Based and Issue-Based Article Analysis
- — Literature-Based Research Projects
- — Reading Scientific Information
- — WebQuest

3. **Designing an Investigation**

   A written plan for scientific inquiry could include the apparatus, materials, safety considerations, and steps to follow. It identifies and controls the major variables.

   - **Identify Variables and Plausible Relationships between or among Variables**
     The key to designing successful experiments is the identification of all variables relevant to both the observed phenomenon and the question posed. Ideally, a scientific experiment is one in which all experimental variables except one are controlled by the experimenter. As the experiment runs, only one variable is free to change, while all others are held constant.
   - **List Materials**
     Students select the appropriate instruments for data collection. Manipulating common tools and lab equipment allows students to create simulations and working models to test their ideas. Students should be able to explain why materials were chosen.

     Example of Strategy:
     — Three-Point Approach—to describe and illustrate materials (*SYSTH* 10.9, 10.22)
   - **Identify Controls**
     Students identify the variables that are controlled and explain why it is important to have those controls.
   - **Generate a Method**
     Upon generating a procedure, students summarize and discuss the method, explain why this is the best procedure, and define terms used.
   - **Identify Safety Considerations**
     Students recognize and identify safety considerations.

     Example of Safety Resource:
     — *Science Safety: A Kindergarten to Senior 4 Resource Manual for Teachers, Schools, and School Divisions* (Manitoba Education and Training)

4. **Implementing the Planned Investigation**

   Teachers may illustrate or demonstrate processes and encourage students to follow their procedures with open minds. Students should maintain an awareness of planned procedures and those followed, noting any changes and why they occurred.

   - **Control Variables**
     Students identify the variable being manipulated and monitor the process to ensure that other variables remain constant.
   - **Repeat Experimental Procedures for Reliability**
     To increase accuracy and reliability, students ensure that they perform an adequate number of trials to make data collection meaningful and replicable.
   - **Demonstrate Safe Work Habits**
     During the course of the procedure, students demonstrate safe work habits.

5. **Observing, Measuring, and Recording**

   Students select and use appropriate methods and tools for collecting data or information. They estimate and measure accurately using the SI system and other standard units. Students should be able to read instruments accurately and explain how measurements and calculations were made.

   - **Collect Data**
     The teacher may model the process of “observing” during data collection. Students concentrate on technique and precision.

     Model observation by asking questions:
     — What does each mark on the...represent?
     — Did you estimate according to a procedure we have recognized as effective...?
     — Would you get the same measurement if...?

Suggestions for Instruction

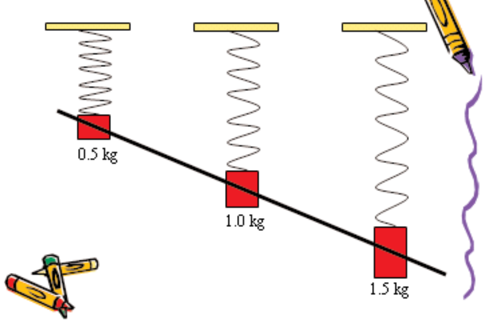
- **Organize and Display Data**
  Students determine what is to be measured before experimentation, and construct a data table accordingly. Teachers suggest and model logical and meaningful ways of organizing and displaying data. Students transform raw data to reveal patterns, reveal relationships between variables, or clarify results. They record, organize, and display observations and data using an appropriate format, including point-form notes, diagrams, sentences, charts, lists, spreadsheets, graphs, and frequency tallies.
- **Report Data Using Various Modes of Representation**
  Data may be represented in various ways within an investigation, using visual, numerical, graphical, and symbolic modes.

  Examples of Modes of Representation:

  — Visual Representation
  - Represent visible relationships among variables (see graphic below).
  - Describe how the experimental run unfolds.

Visual Representation

If we add more mass the spring stretches more.



— Numeric Representation
- Use rounding and significant figures.
- Order data.
- Use error analysis.
- Create charts and/or tables.
- Identify patterns in the raw data.

Numeric Representation

Typically, a visual representation is not enough to determine a relationship accurately. Therefore, we quantify the relationship by making measurements.

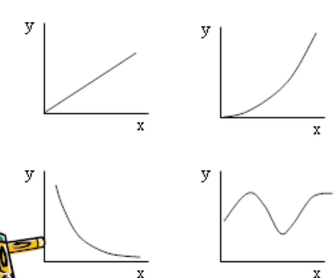
F (N)	X (cm)
1.0	0.2
2.0	0.4
3.0	0.6
4.0	0.8

Students look for patterns emerging in the data (for instance, if force doubles from 1.0 to 2.0, what happens to spring stretch?).

— Graphical Representation
- Use appropriate graph type(s) (e.g., Which graph below matches our spring stretch data?)
- Use correct scaling on axes.
- Tell "the story" from this "picture of the numbers."
- Identify a line of best-fit (e.g., linear regression).
- Interpolate and extrapolate.

Graphical Representation

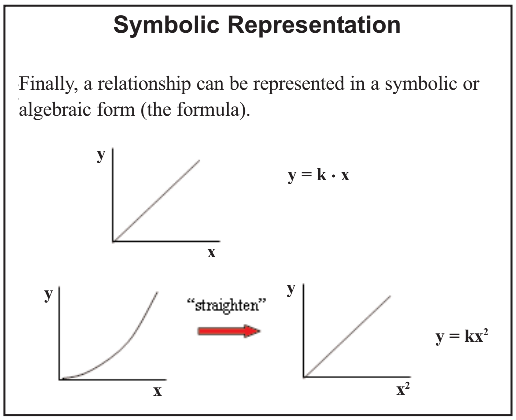
A graph is a "picture" of the numbers.



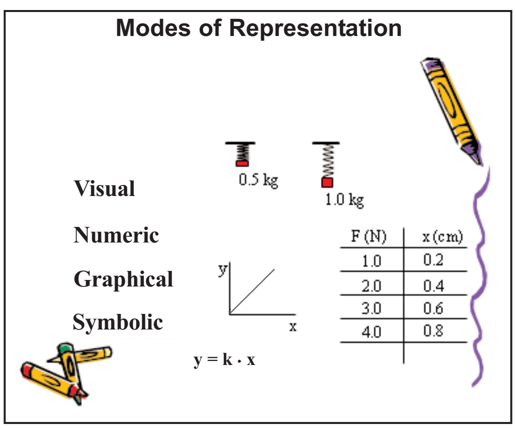
Suggestions for Instruction

— Symbolic Representation

- Determine slope from a linear relationship.
- Connect slope at a particular point on a non-linear curve to an “instantaneous” rate of change.
- Derive model equations for data.
- “Straighten” the curve to determine non-linear relationships.



Summing up the Four Modes of Representation:



6. Analyzing and Interpreting Results

Students analyze data and apply appropriate mathematical and conceptual models to assess possible interpretations and explanations. They select and apply appropriate visual, numeric, graphical, symbolic, and linguistic modes of representation to communicate ideas, plans, and inquiry results effectively.

- **Identify Patterns and Relationships within Results**

  Students should interpret patterns and trends in data, and infer and explain relationships using language such as increasing, decreasing, linear, curvilinear, repeating, unchanging, and extrapolations. Encourage students to talk about the patterns in data, looking at general and specific patterns.

  Model the language for talking about patterns:

  — What do these numbers in the data chart tell us about what occurred?

  — For every change of...in the *dependent* variable, the *independent* variable changes....

- **Propose Explanations and Make New Predictions**

  Students propose explanations and make predictions from their data, identifying limits, exceptions, or alternate interpretations of the data. Guide students back to their background information to compare their thinking with their findings.

  Students identify and suggest explanations for discrepancies in data, including sources of error, such as difficulty in control, insufficient data, inaccurate measurements, equipment limitations, and time constraints.

- **Evaluate Strengths and Deficiencies of Investigation**

  Students evaluate the original plan for investigation and suggest improvements, identifying strengths and weaknesses of data collection methods and design flaws.

Suggestions for Instruction

7. **Concluding and Applying**

   At this stage, students reflect on prior knowledge and experience to develop new understandings. They develop a conclusion that explains the results of the investigation, supporting or rejecting the hypothesis or prediction. Teachers may use divergent and redirecting questioning techniques to help students develop their conclusions. If the data confirms the hypothesis, students state the supporting evidence. They consider cause and effect relationships and make connections to accepted scientific information. Students may also consider alternative explanations, repeat the experiment, and pose questions and hypotheses for further study.

   - **Communicate Results**

     Conclusion(s) should explain the relationship between the independent variable and the dependent variable if that is the design of the scientific inquiry.

     Example of Conclusion for Experiment:

     Here is an example of a conclusion on an experiment that involved *sunlight* and *plant growth:*

     In our experiment, all variables, other than the amount of sunlight, were kept constant. The geranium plants that received additional sunlight did grow more than the plants that were given limited amounts of sunlight. In the 32 days that we ran the experiment, the plants that received an additional 10 hours of sunlight a day grew an average of 3 cm, while the plants that received only limited sunlight grew an average of 1 cm. Our results, therefore, support our hypothesis.

     In addition to revisiting the hypothesis, the conclusion should include the sources of error in the experiment. These would be factors that may impede the accuracy of the data. In the reflections on the process component of the conclusion, the teacher may want to suggest ways to improve the experiment.

     An additional component to the conclusion deals with what implications or applications the experiment or concept has for everyday living.

   - **Use Various Media to Communicate Results**

     Students may present their findings in various ways, depending on the purpose or intention of the inquiry and the results. Inquiry-based results are commonly communicated in the form of a written lab report, a scientific paper, or a presentation. Teachers may structure and facilitate discussions based on a shared understanding of the rules of scientific discourse, such as justifying understandings, basing arguments on data, and critically assessing the explanations of peers. Encourage students to offer their own ideas, to make comments, to debate the validity of explanations and solutions, and to take part in the decision making.

     Examples of Media to Communicate Results:

     — **Written Lab Report**

     Students learn to summarize and analyze laboratory experiences. They may use the following:

     – Laboratory Report Outline (*SYSTH* 11.28-11.29)

     – Formal Lab Report Outline (*SYSTH* 11.38-11.39)

     Students may initially find that generating an entire report is overwhelming, and may get caught up in the *standard format* rather than the actual science that matters. Teachers may choose to spend time developing the parts of the report separately, such as stating the purpose or presenting the data.

     — **Scientific Paper**

     A scientific paper can be a means to identify and attempt to resolve a scientific problem, outline the results of recent research, or examine (to validate) how tests have been conducted to explore key predictions from scientific theory. Students may consider using a scientific writing format that has been agreed upon in consultation with the teacher.

Suggestions for Instruction

— **Presentation**
Scientific inquiry results may be delivered in the form of presentations:
– multimedia presentation (e.g., PowerPoint)
– oral presentation

— **Visual Displays**
Information gathered through the process of scientific inquiry may be communicated through visual displays:
– tables
– graphs
– labelled diagrams
– charts
– posters
– models
– Concept Maps
– cartoons

— **Journal Writing**
Students may reflect and respond to a question using a variety of formats, such as Concept Maps.

Suggestions for Assessment

Assessment techniques such as the following could be applied to the scientific inquiry process:

- **Rubrics/Checklists**
  — Lab Report Assessment (see Appendix 9)
  — Observation Checklist: Scientific Inquiry—Conducting a Fair Test (see Appendix 9)
- **Performance Assessment**
  Assessment strategies may include the following:
  — Demonstrate a lab technique (e.g., lighting a Bunsen burner, using a balance, focusing a microscope).
  — Demonstrate a safety procedure.
  — Interpret Workplace Hazardous Materials Information System (WHMIS) labels.
  — Identify an unknown.

Note:

Develop assessment criteria with students. The criteria should include both content and presentation components and may be similar, regardless of which presentation form students choose. Assign a point value to each criterion, or use a simple rating scale (e.g., excellent, good, fair, poor) for each.

General Learning Outcome C

Students will…

Demonstrate appropriate inquiry, problem-solving, and decision-making skills and attitudes for exploring scientific and/or technological issues and problems.

Specific Learning Outcomes

SLO C2:	Demonstrate appropriate technological problem-solving skills and attitudes when seeking solutions to challenges and problems related to human needs.
SLO C4:	Employ effective communication skills and use a variety of resources to gather and share scientific and technological ideas and data.
SLO C5:	Work cooperatively with others and value their ideas and contributions.

Suggestions for Instruction

Design Process (Technological Solutions)

Problem solving has been defined in many ways. One definition describes a problem as a need that must be met. This need could include, among other things, the need to understand the forces of nature (science), to alter the environment (technology), or to use scientific knowledge to alter the environment (engineering). *Technological problem solving* can be divided into three categories: design, troubleshooting, and technology assessment (impact evaluation).

Technological problem solving is a universal response to human needs and wants. Needs are basic, such as food, shelter, and other things considered essential to survival. Wants are much broader, and include the full range of things people would like to have. Often, a want is perceived by an individual only after an opportunity to meet it is presented. This is frequently the case in our consumer society.

Technological activity involves the application and consumption of resources, including information, knowledge, capital (money), time, raw and synthetic materials, tools, machines, and people. The best possible solutions are identified based on a careful consideration of the problem and available resources. After appropriate evaluation, a solution is adopted. The solution always has outcomes—some known, some unknown, some positive, some negative. Invariably, technological solutions lead to more needs, wants, problems, and opportunities, and the cycle continues.

Technological problem solving often involves the following steps: identifying the problem, postulating possible solutions, testing the best solution, and determining whether the problem is solved. Knowledge and understanding are necessary to solve complex problems and to allow students to transfer learning to other situations.

Design projects are structured around real-world objects. Students may bring some of their knowledge of the world to their design. In addition to deciding what a design will look like, students identify what they want the design to do and how they will evaluate whether it meets that goal. Design projects provide a context for scientific communication. In an open-ended design context, knowledge acquired by one may be applied by all, in very different ways.

Since testing designs produces data that may be used as evidence, students have opportunities to present and critique scientific arguments that explain the performance of different designs.

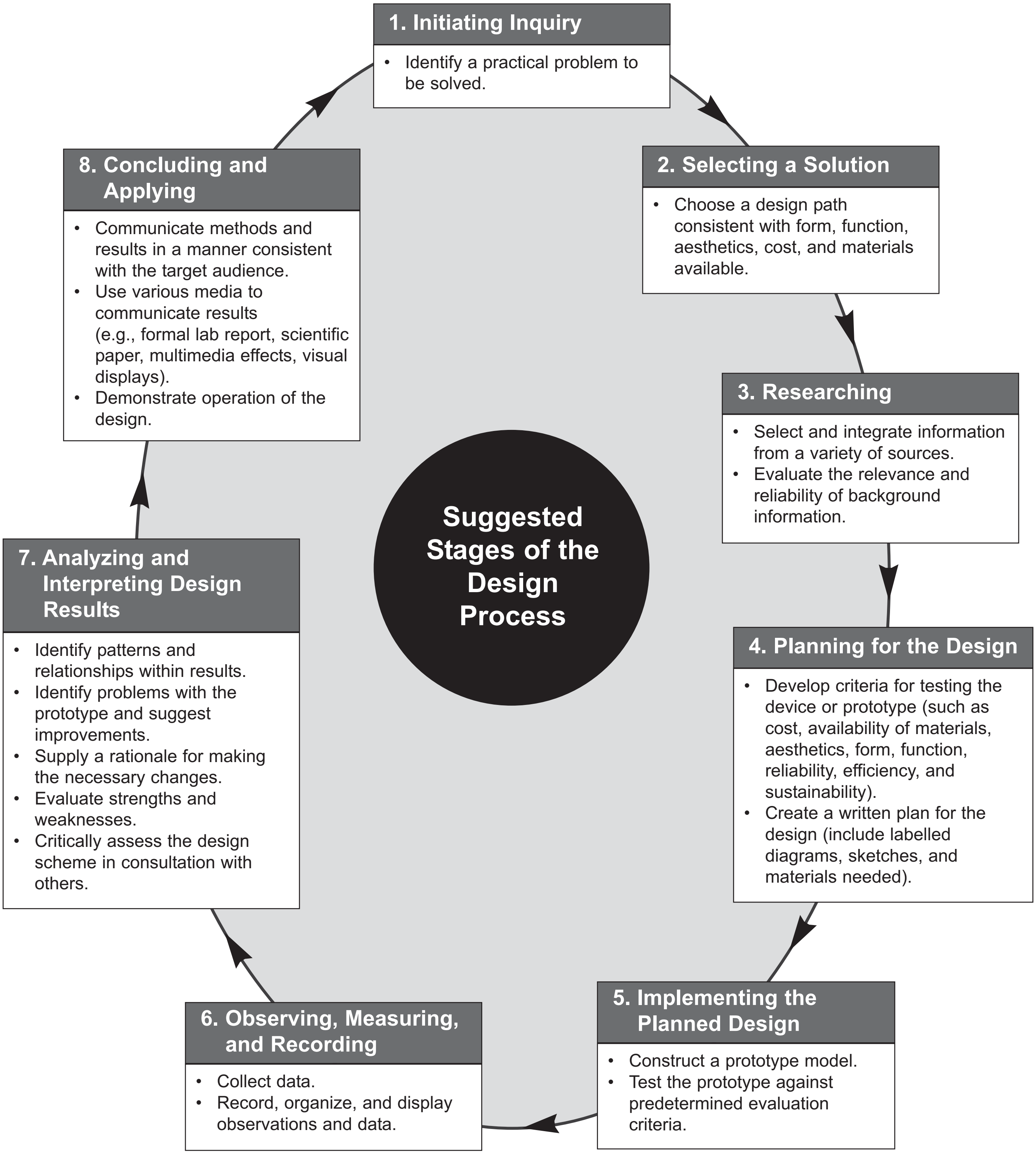
Students propose, build, test, evaluate, and redesign their designs. Design challenges may be posed to students, or students may have the responsibility of deciding for themselves what object they will design for what purpose. Guiding questions, posed by written activities, the teacher, and structured design journals, emphasize explanation and prompt students to focus their experimentation on explanation as well as performance. Initial activities that lead up to the design task provide students with an understanding of scientific principles they can apply to their designs, and also model the process of pursuing answers to scientific questions.

Providing opportunity for redesign has several benefits. First, it gives students a chance to apply what they learned from building and testing earlier designs. Testing may also uncover new constraints or important properties that lead students to revise their experiments and redefine the questions, methods, and means of testing they have been pursuing. When teaching design, teachers need to develop a strategy that not only tolerates but also rewards alternative solutions.

The diagram that follows illustrates the suggested Stages of the Design Process: Constructing a Prototype.

Suggestions for Instruction

Stages of the Design Process: Constructing a Prototype



Suggestions for Instruction

Overall Expectations

Students could achieve the identified learning outcomes through learning experiences such as the following:

- Construct a prototype and test the device.
- Observe, measure, record, organize, and display data using appropriate formats such as labelled diagrams, tables, and graphs.
- Analyze data improvements.
- Select and apply appropriate visual, numeric, graphical, symbolic, and linguistic modes of representation to communicate ideas, plans, and inquiry results effectively.
- Communicate questions, ideas, and intentions, as well as receive, interpret, understand, support or refute, and respond to the ideas of others with models. (For example: *Participate in a group activity where the positions of Earth's continents at various times in the past are shown with three-dimensional models of Earth. Modelling clay could be used as the continental pieces attached to a globe. Can a good "fit" of the continents be achieved on an Earth of modern radius, or are there unexplainable gaps? How would two different theories—plate tectonics or the expansion of the Earth—respond to the problems that arise when we perform such "puzzle fits" of the continents?*)
- Select and integrate information from various print, electronic, and multimedia sources, and compile and organize information using appropriate formats and data treatments.
- Identify and apply criteria for evaluating evidence and sources of information, including the presence of bias.
- Work collaboratively in planning and carrying out investigations, and in generating and evaluating ideas.
- Listen, evaluate, and respond to the individual or group work of others, including an assessment of the credibility, accuracy, and potential biases of information presented.

Activating

Entry-Level Knowledge

- Throughout Kindergarten to Grade 8, students develop the design process. They construct prototypes to solve practical problems and analyze them according to criteria such as cost, efficiency, and environmental considerations.
- In the Senior Years, students continue this continuum at a greater level of expectation for sophistication. Students continue to apply their problem-solving skills in the evaluation of consumer products to determine the best product for a particular purpose. They are able to identify practical problems to solve. Students locate, evaluate, and summarize relevant information from a variety of sources, develop evaluation criteria, and create a plan to solve a problem. Students construct and test a prototype using observational, measurement, and recording skills. They work cooperatively to collect, organize, and display data. Students evaluate the prototype and identify a solution to the problem. In addition, students develop key attitudes, an initial awareness of the nature of science, and other skills related to research, communication, the use of information technology, and cooperative learning.

Prior Knowledge Activities

- Learning activities and strategies such as the following allow teachers and students to activate prior knowledge, recognize misconceptions, and relate new information to prior experiences.

  Examples of Strategies (See Appendices 2 and 3):

  — Anticipation Guide
  — Discrepant Event
  — Drawing
  — Knowledge Chart
  — KWL
  — LINK
  — Listen-Draw-Pair-Share
  — Rotational Cooperative Graffiti
  — Sort and Predict

Suggestions for Instruction

Vocabulary-Building Activities

- Learning activities and strategies such as the following allow teachers to assist students in accessing the vocabulary they already know or prepare them to learn vocabulary so that they will better understand new material.

  Examples of Strategies (See Appendix 3):

  — Sort and Predict

  — Three-Point Approach

  — Webs and Clusters

The Stages of the Design Process

1. **Initiating Inquiry**
   - **Identify a Practical Problem to Be Solved**
     Students carefully analyze the design problem and break it into the smallest systems and subsystems possible. They clarify the problem to determine exactly what they have been asked to create or design. Students devise and implement a strategy that employs a variety of sources for identifying and investigating real-life communication problems and opportunities. They identify and clearly state needs, problems, and opportunities related to human-human, human-machine, and machine-machine communications. Finally, they develop a design brief that clarifies and states the communications problem to be resolved.

     For example, a practical problem for solution such as "*use the design process to construct a prototype device that determines time of day from the sun's shadow"* could be presented in the following manner:

     > *Design and construct a prototype device that determines time of day from the sun's shadow for a group of wilderness athletes on an adventure race. The athletes will not carry any watches or clocks, and need to arrive at a particular destination for pick-up at a specified time.*

     Students, ideally, should be involved in the problem identification. The problem should be framed within a context. This might involve a real-world problem or a scenario linked to another discipline, such as social studies or literature selection. It is critical that the design challenge presented to students is problem focused, as opposed to product focused. For example, "construct a boat" is a product-focused challenge, while "construct a floating device to transport a load of three blocks across a span of water one metre wide" is a problem-focused challenge. The problem must also be open-ended to encourage optimum solutions.

     Examples of Strategies (See Appendices 2 and 6):

     — Brainstorming

     — Class or Group Discussion

     — Listen-Think-Pair-Share

     — Rotational Cooperative Graffiti

     — Roundtable

2. **Selecting a Solution**
   - **Choose a Design Path**
     Students create as many solutions to the design problem as possible before attempting to implement any of them. They choose a design path consistent with form, function, aesthetics, cost, materials, and so on. Design teams ask questions such as the following.

     Examples of Questions:

     — Are there other ways to solve this problem or use these materials?

     — Can I borrow, adapt, or extend existing solutions or technologies?

     — Can I add a new element or twist that might lead to a solution?

     — Can I add more to the problem in an effort to find a solution?

     — Can I remove parts of the problem in an effort to solve it?

     — Can I incorporate substitutes or use other materials or technologies?

Suggestions for Instruction

— Can I rearrange the elements of the problem to find the solution?
— Can I do the opposite of what I am currently thinking?
— Can I combine elements or technologies to solve the problem?
— Can I examine the range of ideas explored and the strategies used in the design brief as a means of improving the solution and presenting a coherent plan for developing the solution?
— Can I develop multiple options for a solution and identify the most appropriate solution, considering conservation of resources, suitability of the solution, outcomes of the solution, and the technical activity required to produce it?

3. **Researching**

The research portion of the design process may take place at various stages.

- **Select and Integrate Information from a Variety of Sources**
It is important that students select and integrate information from a variety of sources, compiling and organizing information using appropriate formats and treatments.

- **Evaluate Relevance and Reliability of Background Information**
Students identify and apply criteria for evaluating evidence and sources of information, examining the reliability, bias, and usefulness of information gathered. They then summarize and record the information in a variety of forms, including paraphrasing, quoting relevant facts and opinions, and referencing. Students may incorporate knowledge, concepts, and problem-solving strategies from other disciplines in solving technological problems.

Examples of Sources:
— **Print**
  – texts
  – newspapers
  – journals
  – magazines
— **Electronic**
  – Internet
  – videos
  – CD-ROM
  – television
— **Community**
  – resource people

Examples of Strategies (see Appendices 4 and 5):
— Article Analysis Frames
— Case Studies
— Concept Mapping
— Fact-Based and Issue-Based Article Analysis
— Literature-Based Research Projects
— Reading Scientific Information
— WebQuest

4. **Planning for the Design**

- **Develop Criteria for Testing the Device or Prototype**
Students develop and apply appropriate objective and subjective criteria for evaluating a need. Design specifications and design studies may take into account aesthetics, function, quality construction, and the user. 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. It is also important that the criteria are *testable*.

Suggestions for Instruction

Criteria should be generated with student input. They should also be framed in the context of the science learning within the cluster of targeted learning outcomes. The teacher may need to specify certain criteria related to the learning outcomes and available materials, whereas students will often identify "real-life" types of criteria. In developing criteria, students should address function, cost, and aesthetics.

To ensure that each of the specified criteria is testable, students need to provide descriptors. These might include the following:

— **Aesthetics:** For some prototype solutions, aesthetics are an important factor. The criterion of being "visually appealing" can be included, but further descriptors (e.g., colour, scale, finishing) facilitate evaluation.

— **Cost:** The inclusion of cost heightens student awareness of issues of product production and cost-effectiveness. This criterion can be included by assigning a monetary value to materials or processes involved in the construction of the prototype.

— **Form, Function, Reliability, and Efficiency:** Criteria addressing the form, function, reliability, and/or efficiency of the prototype must be clearly specified to ensure consistency in testing. These criteria often have a strong overlap with the scientific inquiry process, as the concept of a "repeatable, fair test" is applied.

— **Sustainability:** Criteria that include the use of recycled materials or environmental considerations focus student awareness on sustainability and the potential environmental impacts of design solutions on the environment. This links with the Science, Technology, Society, and Environment (STSE) component of the Senior 3 Current Topics in the Sciences curriculum.

- **Create a Written Plan for the Design**
  At this stage, the group of students generates several ideas and selects the best possible solution to the proposed problem. The teacher assists in activating students' creative thinking skills of fluency, flexibility, elaboration, and originality. This will encourage optimum solutions to the problem. The group then identifies appropriate materials, safety considerations, and a logical sequence of steps to follow. Students record their plan, including labelled diagrams of the top and side views of the prototype, and three-dimensional sketches where possible. It is important that students are aware of the value of the labelled sketch. It provides a visualization of the prototype to guide the construction and serves as a draft blueprint. The constructed prototype can be (and likely will be) altered from the initial sketch, and an explanation of the need for changes is an important aspect of student learning. In creating a plan for the design and construction of the prototype, it is useful to have students include a plan/instrument to test the prototype according to the criteria identified and following a fair-test approach.

  Students create a written plan, in which they

  — specify a timeline

  — assign tasks

  — list materials (students explore a broad range of tools, materials, and processes)

  — identify safety precautions

  — draw diagrams (showing design changes)

5. **Implementing the Planned Design**
   - **Construct a Prototype Model**
     Constructing the designed prototype gives students opportunities to apply their understanding of the properties of materials and their uses. It encourages students to identify information needs and to access the required information through research. In addition, it enables students to apply the science knowledge and skills they have acquired through that particular science cluster in a practical context.

Suggestions for Instruction

For example, a design problem associated with a specific problem such as "*use the design process to construct a structure that will withstand the application of an external force*" requires students to apply the following knowledge and skills:

- Identify internal and external forces and the stress they apply to structures.
- Identify the centre of gravity and its effect on stability.
- Determine the efficiency of the structure as it relates to mass, investigating the effect of a force in terms of its magnitude, direction, plane, and point of application.
- Determine methods to increase the strength and stability of a structure.

Students require experience with key concepts and skills prior to the design project. 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 plan.

- **Test the Prototype against Predetermined Criteria**
  Students test the prototype against the predetermined evaluation criteria. They select and use appropriate tools and instruments to conduct a fair and consistent test. Students will use accurate estimates and measurements and record their observations and results. Students often need to be reminded that their prototype must address *all* the criteria identified.

6. **Observing, Measuring, and Recording**
   Students select and use appropriate methods and tools for collecting data or information. They estimate and measure accurately using the SI system and other standard units. Students should be able to read instruments accurately and explain how measurements and calculations were made.

- **Collect Data**
  Teachers may model the process of "observing" during data collection. Students concentrate on technique and precision when making their design operational.
  Model observation by asking questions:
  - What does each mark on this object represent?
  - Did you estimate according to a procedure we have recognized as effective...?
  - Would you get the same measurement if...?
- **Record, Organize, and Display Data**
  Students determine what is to be measured before experimentation and construct a data table accordingly. Teachers suggest and model logical and meaningful ways of organizing and displaying data. Students transform raw data to reveal patterns, reveal relationships between variables, or clarify results. They record, organize, and display observations and data using an appropriate format, including point-form notes, diagrams, sentences, charts, lists, spreadsheets, graphs, and frequency tallies.

7. **Analyzing and Interpreting Design Results**
   In the analyzing and interpreting stage of the design process, students
   - identify patterns and relationships within results
   - identify problems with the prototype and suggest improvements
   - supply a rationale for making the necessary changes
   - evaluate strengths and weaknesses
   - critically assess and evaluate their own and others' products and systems, particularly for aesthetics, appropriateness, quality, resource usage, performance of materials, production methods, and economic and social considerations

Suggestions for Instruction

8. **Concluding and Applying**

   In the concluding and applying stage of the design process, students propose and justify a solution, identify new problems, and reflect on prior knowledge and experiences. They present an evaluation of their own and others' products, in which they address the relationship between materials chosen and procedures and processes used, note suggestions for and justification of possible improvements, comment on suitability of the product for manufacture, and estimate the effects and costs, including environmental and economic considerations.

   - **Communicate Methods and Results**
     Students communicate methods, results, conclusions, and new knowledge in a manner consistent with their target audience.
   - **Use Various Media to Communicate Results**
     Students may present their results in various ways.

     Examples of Media to Communicate Results:

     — **Formal Lab Report**

     — **Scientific Paper**

     — **Presentation**
       – multimedia effects

     — **Visual Displays**
       – bulletin boards
       – cartoons
       – charts
       – Concept Maps
       – demonstrations
       – diagrams
       – dioramas
       – graphs
       – maps
       – models
       – newspaper/magazine advertisements
       – posters
       – radio commercials
       – television commercials
       – videos

     — **Community Connection**
       – Invite local members of the community to share their technological problem-solving knowledge with the class. Students could also interview community members in their homes or workplaces about a problem they have been applying themselves to solve.
       – Organize field trips to facilities that demonstrate clearly how solutions to problems often rely upon the eventual development of new processes or technologies. For instance, some paper-recycling facilities are unique in their ability to "de-ink" paper fibre that has undergone xerography, the application of a baked carbon film.

     — **Journal Writing**
       – Compare and Contrast (*SYSTH* 10.24)
       – Concept Frame (*SYSTH* 11.36)
       – Concept Map (*SYSTH* 11.14)
       – Concept Overview (*SYSTH* 11.37)
       – Fact-Based or Issue-Based Article Analysis (*SYSTH* 11.40, 11.41)
       – RAFTS (Role-Audience-Format-Topic-Strong Verb) (*SYSTH* 13.23)
       – Reflect on and Respond to a Question
       – Word Cycle (*SYSTH* 10.21)
       – Word Glossary
   - **Demonstrate Operation of the Design**

Suggestions for Assessment

Learning outcomes addressed through the application of the design process, like other areas of the curriculum, are assessed for the acquisition of knowledge, skills, and behaviours. A variety of assessment practices can be applied to the performance of a design task, including teacher observation, questioning, and student learning logs or notebooks.

It is important that the focus of assessment be on the demonstration of learning that has occurred throughout the design process. Similarly, the solution should not be evaluated on whether it worked, 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 evaluation are ongoing. The design process also provides opportunities for formative assessment so that the teacher can plan the next stage of instruction and learning.

In the evaluation stage of the design process, assessment focuses on the positive aspects of the solution. Through the use of probing and open-ended questions, the teacher can elicit further thinking on making improvements to enhance the solution and to enhance student understanding of the science knowledge connected to the design task. This will also provide indicators as to students' level of achievement related to the learning outcomes. Design notebooks, demonstrations, oral presentations using visuals, and multimedia presentations can provide records of student learning at each stage of the design process and assist in the assessment of student learning.

A brief list of assessment techniques that could be applied within the context of the design process follows:

- **Rubrics/Checklists**
  - — Developing Assessment Rubrics in Science (see Appendix 8)
  - — Assessment Rubrics (see Appendix 9)
- **Visual Displays**
- **Journal Writing**
  - — Journal Writing and Assessment (*SYSTH* 13.21)
  - — Word Cycle (*SYSTH* 10.21)
- **Research Reports/Presentations**
- **Performance Assessment**
- **Pencil-and-Paper Tasks**
  - — Compare and Contrast (*SYSTH* 10.24)
  - — Concept Relationship Frame (*SYSTH* 11.20, 11.35)
  - — Fact-Based or Issue-Based Article Analysis (*SYSTH* 11.40, 11.41)
  - — Word Cycle (*SYSTH* 10.21)

General Learning Outcome C	Specific Learning Outcome	
Students will... Demonstrate appropriate inquiry, problem-solving, and decision-making skills and attitudes for exploring scientific and/or technological issues and problems.	**SLO C3:**	Demonstrate appropriate critical thinking and decision-making skills and attitudes when choosing a course of action based on scientific and technological information.
	SLO C4:	Employ effective communication skills and use a variety of resources to gather and share scientific and technological ideas and data.
	SLO C5:	Work cooperatively with others and value their ideas and contributions.

Suggestions for Instruction

Science, Technology, Society, and Environment (STSE) Issues and Decision Making

Students are increasingly confronted with questions that require the processing of information and demand the use of scientific thinking to make informed decisions. Given the opportunity, students should be able to make an informed decision based upon a methodology that is rational and scientific. Because students have different experiences and interests, they do not all view a problem in the same way. It is essential that educators provide students with opportunities to gain experience in mastering the skills of informed decision making.

Traditional decision-making models are focused on values, attributes, goals, alternatives, and *subjective mapping*. This mapping includes data collection, statistical analysis, and research models that help the decision maker evaluate possible alternatives. The subjective mapping between criteria and attributes is provided by the decision maker. To clarify the criteria that argue for a particular course of action, students need to know why certain criteria were necessary. The attributes of the problem to be solved ultimately drive the criteria used in assessing the situation.

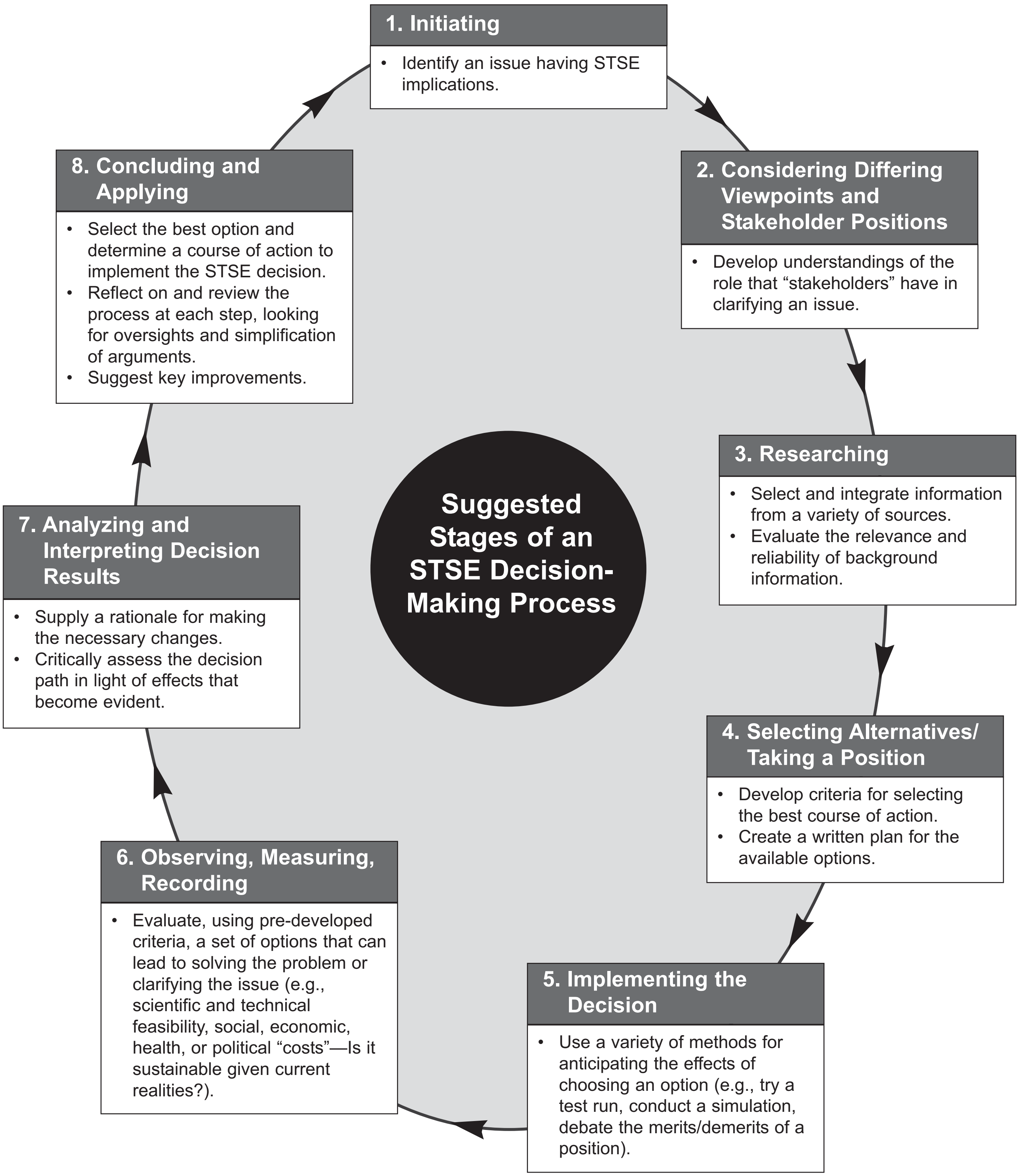
STSE understandings are an essential component of scientific literacy. An STSE approach fosters the development of citizens who are able to evaluate scientific information critically, understand the relationships amongst science, technology, society, and the environment, and make informed and responsible decisions, as well as act on these decisions. STSE issues are often complex, with no one right answer. They can also be controversial, as they deal with individual and group values. By their nature, STSE topics generate diverse opinions; individuals must question the distinctions between right and wrong, cost and benefits, and justice and injustice, and develop interpretations of fairness and tolerance. They include topics on which reasonable people may sincerely disagree. Students are encouraged to exercise both intellectual and ethical skills as they investigate the social and environmental impacts of scientific and technological developments (refer to *SYSTH* 4.4-4.5).

The decision-making process is a proposed approach for analyzing STSE issues and making a choice among different courses of action. To make an informed decision, students must understand scientific concepts involved in the issue and must be aware of the values that guide a decision. The process can involve a series of discrete steps, which may include those described on the following pages. One should also recognize that this is but one possible sequence—of a rather concrete nature—that has demonstrated its usefulness with student audiences. Teachers are encouraged to use this as a beginning template toward more sophisticated STSE approaches with Senior 3 students.

The diagram that follows illustrates the Stages of the Decision-Making Process: Toward STSE Thinking.

Suggestions for Instruction

Stages of the Decision-Making Process: Toward STSE Thinking



Suggestions for Instruction

The decision-making process involves the following stages:

1. **Initiating:** Identify and clarify the issue.
2. **Considering Differing Viewpoints and Stakeholder Positions:** Be aware of the different perspectives and interests involved in the issue.
3. **Researching:** Critically evaluate the available research.
4. **Selecting Alternatives/Taking a Position:** Determine possible alternatives or positions related to an issue.
5. **Implementing the Decision:** Evaluate the implications of possible alternatives or positions related to an issue.
6. **Observing, Measuring, and Recording:** Make use of criteria in order to assess the feasibility of a decision.
7. **Analyzing and Interpreting Decision Results:** Make a thoughtful decision and provide justification. Be aware of the values that may guide a decision.
8. **Concluding and Applying:** Act on a decision and then reflect on the process that led to a course of action.

Students have been introduced to the Decision-Making Model in Senior 1 Science. At Senior 3, in a curriculum such as Senior 3 Current Topics in the Sciences, students should be expected to deal with some larger-scale contexts, but the primary focus rests with local and personalized ones, to consider complex problems with *a small number of variables* and/or perspectives, and make their decisions based on extensive research involving some guided personal judgement. If students don't possess experience with an STSE decision-making model, teachers can start the process with some guidance, giving students a chance to use this approach in a structured environment. This could be done by giving them a specific scenario or issue to study. Students would eventually become active participants in the process, by choosing (individually, in small groups, or as a class) their own issues, doing their own research, making their own decisions, and acting on those decisions.

The decision-making process can be approached in a variety of ways. For instance, students can play the role of different stakeholders involved in an issue, work in small groups to discuss issues, or make a decision based on their own research and personal values. Students can be asked to take a stand and debate issues, or they can be placed in situations where they have to reach a consensus. Because there are so many different ways of approaching an issue, a variety of products or culminating events can result from a decision-making process (for example, a town hall meeting, a round table, a conference, a debate, a case study, a position paper, a class presentation, or a class discussion).

Regardless of what product students have to create or what event they have to participate in, questions such as the following can guide them in the decision-making process:

- What is the issue?
- What important scientific information is needed to understand this issue? Where can I find this information?
- Who has a stake in this issue? Why?
- What are the possible options?
- What are the pros and cons for each of the possible options?
- What is my decision? What criteria were used to make this decision?

Suggestions for Instruction

An STSE Decision-Making Guide

The Issue	State the issue in clear terms.
The Decision Question	The wording of the question is quite important, as it may affect the decision and ultimate outcomes.
Type of Decision Required	A question may involve • a scientific, technological, legal, political, or moral decision that is to be made • a public policy decision—a decision that prescribes ways of handling a situation of interest to the broader community
Possible Choices	Identify alternatives as they develop. Some decisions may have only two alternatives (for example, *build it* or *do not build it*), while others will have more than two.
Risk/Benefit Analysis	For each alternative, list the negative consequences and the positive consequences of taking the action.
Validity and Probability	Carefully check the *validity* of your risk/benefit arguments for each alternative. • Are your conclusions logical? • Are they based on false assumptions? • How *probable* are your conclusions in reality?
Values Assumed	Identify the values within each alternative. • Examples of values include: generation of capital (wealth) for a country, being in harmony with natural systems, causing no harm to people, practising justice, the rule of law, and honest intentions. • The values you include may not necessarily be your own personal values; nonetheless, you must recognize them and clarify them. • As you identify values, ask yourself questions. What things would people highly value if they strongly believed in Alternative 1 over Alternative 2?
Priority of Values	Rank the values that have been assumed in hierarchical order from most to least important.
Choice of Option(s) and Reason(s)	Weigh the consequences and consider the logic of your thinking, the probabilities, and your values. Then choose an option.
Action Recommended	Decide what action(s) should be taken, by whom, and when.

(continued)

An STSE Decision-Making Guide: Adapted from Aikenhead, Glen. *Logical Reasoning in Science and Technology*. Trial Version 2. Saskatoon, SK: Department of Curriculum Studies, University of Saskatchewan, 1987. Used with permission of Glen Aikenhead.

Suggestions for Instruction

An STSE Decision-Making Guide *(continued)*

Issue:			
Decision Question:			
Type of Decision:			
Possible Choices	**Risk/Benefit Analysis**	**Validity and Probability**	**Values Assumed**
Alternative 1	Negative Consequences:		
	Positive Consequences:		
Alternative 2	Negative Consequences:		
	Positive Consequences:		
Alternative 3	Negative Consequences		
	Positive Consequences		
Alternative 4	Negative Consequences		
	Positive Consequences		

(continued)

Suggestions for Instruction

An STSE Decision-Making Guide *(continued)*

Priority of Values (from most to least important):
Choice of Option(s) and Reason(s):
Action(s) Recommended (what, by whom, when):

Suggestions for Instruction

Overall Expectations

Students could achieve the identified learning outcomes through learning experiences such as the following:

- Know, respond to, and accept scientific inquiry as a means to developing new understandings of both the simplicity and complexity of natural systems.
- Model curiosity, skepticism, creativity, open-mindedness, accuracy, precision, honesty, and persistence.
- Use factual information, rational explanations, and persuasive argumentation when analyzing, evaluating, and communicating.
- Select and apply appropriate visual, numeric, graphical, symbolic, and linguistic modes of representation to communicate ideas, plans, and inquiry results effectively.
- Communicate questions, ideas, and intentions, as well as receive, interpret, understand, support or refute, and respond to the ideas of others. (For example: *Participate in a class discussion of the geological evidence suggesting that continental positions have changed in response to the mechanisms of plate tectonics or the expansion of the Earth.*)
- Select and integrate information from various print, electronic, and multimedia sources, and compile and organize information using appropriate formats and data treatments.
- Identify and apply criteria for evaluating evidence and sources of information, including the presence of bias.
- Work collaboratively in planning and carrying out investigations and in generating and evaluating ideas.
- Listen to, evaluate, and respond to the individual or group work of others, including an assessment of the credibility, accuracy, and potential biases of information presented.

Activating

Entry-Level Knowledge

- Students begin to make decisions based on scientific facts and refine their decision-making skills as they progress through the grades, gradually becoming more independent. Students also develop key attitudes, an awareness of the nature of science, and other skills related to research, communication, the use of information technology, and cooperative learning. Senior Years students recognize that STSE issues require a more sophisticated treatment through the decision-making process.

Prior Knowledge Activities

- Learning activities and strategies such as the following allow teachers and students to activate prior knowledge, recognize misconceptions, and relate new information to prior experiences.

  Examples of Strategies (See Appendices 2 and 3):

  — Anticipation Guide
  — Knowledge Chart
  — KWL
  — Listen-Draw-Pair-Share
  — LINK
  — Sort and Predict
  — Rotational Cooperative Graffiti

Vocabulary-Building Activities

- Learning activities and strategies such as the following allow teachers to assist students in accessing the vocabulary they already know or prepare them to learn vocabulary so that they will better understand new material.

  Examples of Strategies (See Appendix 3):

  — Sort and Predict
  — Three-Point Approach

Suggestions for Instruction

Acquiring and Applying Activities

Role-Play

Role-playing scenarios are designed to teach selected social processes that govern human relations, such as negotiating, bargaining, compromising, and developing sensitivity. Role-playing is an effective way to get students to examine the values of others and how those values guide decisions. Students should not always defend a point of view with which they agree. They need to put themselves in someone else's mindset, and speak from that individual's point of view during the activity. It is hoped that through this process students will gain an appreciation for the reasons why individuals hold divergent points of view. Ideally, the role-playing scenario will foster critical thinking skills, while promoting tolerance of alternative world views (see *SYSTH* 4.18).

- Role-playing activities can deal with many types of issues. For instance, a town-hall meeting activity could be used to deal with a local issue such as a proposed condominium development close to a city park (see teacher background on preparing activities for a town-hall meeting).
- Students could also take part in a role-playing activity in which a consensus between stakeholders must be reached, such as a round-table meeting or an international conference. The format would be similar to that of a town-hall meeting, but all stakeholders must come to a consensus. Explore with students what consensus means and how it differs from other forms of decision making.

Consensus is	Consensus is not
• based on identifying common ground	• based on majority rule
• reached by acceptable compromises	• reached by complying with the most outspoken group member
• always a decision that reflects the ideas and values of all group members	• always a decision that represents everyone's first choice

When studying STSE issues, a consensus approach can use the sustainable development model, which tries to achieve consensus by balancing the needs of human health and well-being, the environment, and the economy (see Manitoba Education and Training, *Education for a Sustainable Future* 14-16).

Town-Hall Meeting (Teacher Background)

1. Assign the role of different stakeholders (e.g., scientists, company executives, developers, Chamber of Commerce representatives, town residents, conservation officer, politicians, lawyers, environmentalist) to groups of students, and give them time to research and compile their arguments. They prepare a five-minute presentation to present their position, as well as notes to help them answer possible questions.
2. Prepare an agenda for the meeting, indicating a speaking order for the different stakeholders. As the moderator of this meeting, ensure that students respect the time given to present their position and give time for questions either after every speaker's presentation or after all stakeholders have presented their positions.
3. Give five minutes for every stakeholder to present and defend his or her position.
4. Stakeholders can then ask questions or direct comments to different stakeholders. To ensure that all students participate, focus part of their evaluation on their participation during the meeting.
5. Have students vote on the proposition at the end of the meeting (either with raised hands or with a secret ballot). Or, bring in a "town council," which could be another group of students from the class (who would write a report with their recommendation and impressions, indicating which stakeholders they believed and/or didn't believe and explaining why), from another class, or other teachers, administrators, or support staff.

Suggestions for Instruction

For examples of how the process could unfold in a classroom, refer to the activities suggested in the Appendices of this document. Any issue chosen by students could be addressed by using these types of activities. They could also be used as a guided activity to model a decision-making process before students study their own issues.

- Ask students about the importance of having everyone contribute during the role-playing activity (that is, hearing all voices). Have them answer questions such as the following in their science journals:
  - — Did you feel this situation actually occurred?
  - — Did you feel you were able to role-play well?
  - — Did you agree or disagree with the viewpoints of your character?
  - — What did you like or dislike about the activity?
- Students present their own view on the issue in a form such as a position paper, a letter to the editor, a news bulletin, and so on.

Online Resources for Role-Play

The following websites present ideas for role-playing activities.

ActionBioscience.org: <http://www.actionbioscience.org/lessondirectory.html>

Endorsed by the National Association of Biology Teachers, this website provides students and their teachers with opportunities to examine science content in the context of the scientific paper. The lessons are set up in such a manner that some interaction between the content of the scientific paper and the actual science content required for the classroom can be examined.

Australian Academy of Science. NOVA: Science in the News: <http://www.science.org.au/nova/topics.htm>

This website provides such a wide variety of topics and lessons (from mathematics, to physics, technology, biosciences, human health, the environment, and so on) that it will provide interesting current contexts for Senior 3 Current Topics in the Sciences for years to come.

Kemlitz, Judith, Michael O'Hare, and Dorothy Reardon. "Rainforests of Madagascar: Role Playing and Decision Making." Access Excellence @ the National Health Museum. 6 Jan. 2006 <http://www.accessexcellence.org/AE/AEPC/WWC/1991/rainforest_role.html>

In this "jigsaw-like" approach to threatened rainforests of the island of Madagascar, students develop their understanding of the skills and stakeholder positions often found in contentious issues. The results can be generalized across many similar situations related to environmental degradation.

Mills, Don. "Darwin/Lamarck Court Case." Access Excellence @ the National Health Museum. 6 Jan. 2006 <http://www.accessexcellence.org/AE/ATG/data/released/0078-DonMils/>

In this activity-based role-playing exercise, students take on the respective positions of Darwin and Lamarck (who were not contemporaries) in a courtroom setting. This debate format has become a favourite among teachers who appreciate the value of taking individuals out of time and artificially asking them to defend their ideas in front of their futuristic colleagues.

Nelson, Sharon. "Decisions, Decisions! A Genetics Role-Playing Activity." Access Excellence @ the National Health Museum. 6 Jan. 2006 <http://www.accessexcellence.org/AE/ATG/data/released/0350-SharonNelson/>

For this role-playing activity, students use research skills to investigate a particular human genetic disorder, and then develop a class presentation that explores bioethical considerations.

Suggestions for Instruction

Position Paper

A position paper is a written product that presents an opinion. Its goal is to convince others to agree with a point of view. A position paper can be assigned instead of role-play. It can also be assigned after role-play in order for students to write their own views on an issue. Position papers may contain a description of an issue and scientific knowledge surrounding the issue, arguments and evidence for both sides of an issue, a refutation of the opposing claim, and the viewpoint adopted, along with reasons why.

More detailed information about writing a position paper follows. An important component of this type of paper is the referencing of information and quoting of sources. The learning outcomes related to research and information management can provide useful strategies for teaching and assessing these skills.

Debating

Debates are effective at presenting diametrically opposed views related to STSE issues. For a formal debate, teams of students would either be assigned a position on a certain issue or they would choose a position with which they agree. Teachers can also ask a team of students to provide the necessary background for the audience to understand the topic before the formal debate begins. The presenters should go over the information with the debaters prior to the debate.

There are many possible formats for using debates in a classroom. Here is one example:

1. Initial presentation provides background so that the audience understands the topic (3 to 4 minutes).
2. First debater presents opening arguments (2 to 3 minutes). Arguments should be presented and supported with evidence such as statistics or quotes.
3. Second debater presents opening arguments (2 to 3 minutes).
4. First debater gives a rebuttal (1 to 2 minutes).
5. Second debater presents defending arguments (1 to 2 minutes).
6. Second debater gives a rebuttal (1 to 2 minutes).
7. First debater presents defending arguments (1 to 2 minutes).
8. Closing statements are presented (1 minute each).

Position Paper (Student Background)

- **Choosing an Issue for a Position Paper:** A good issue will have an element of controversy and will have at least two clear positions. Choose an issue that is of personal interest to you, and is manageable. You may already have an opinion about this issue, but you will need to research it to construct your arguments and to present a balanced view of the opposing position. After doing some research, your personal opinion about the issue might change. Listing pros and cons about the issue, along with evidence supporting the claims can help you in preparing your paper. Don't forget to reference the sources for all your information.

  You must also consider what audience you are writing for. Your task is to convince your audience to agree with your position; therefore, you must speak in a language that the audience will understand. For example, a paper written to convince your teacher would be written differently than a paper written to convince your friends.
- **Introduction:** Identify the issue and give some background information on it. What is the issue? Why is this issue important? What are some potential impacts of this issue? You can choose not to give opinions for or against the issue (just present the issue and its importance), or you can state your position without presenting all the supporting evidence for it. You want to create a context for your topic, stimulate the reader's interest about the topic, and then state your claim about the issue. The next step will be to provide some proof in order to support your claim.
- **Supporting Arguments:** Provide arguments that support the issue. You must provide evidence for your arguments (facts, statistics, authoritative testimonies). Leave out your opinions. Be thorough and fair and always cite your sources. You can directly quote from them or refer to them. Don't forget to jot down information in order to create a bibliography. The reader of your paper has to know where your evidence comes from. You must use at least three different sources when presenting the supporting arguments.
- **Opposing Position:** Present arguments for the opposing position. You must provide evidence for the arguments. Leave out your opinions. Use at least three different sources when presenting the arguments against an issue. It is best to choose one or two arguments and then develop them in depth.
- **Your Position:** State a position, along with a justification. This is where you can voice your own opinions. You can also refer to the facts, opinions, or data mentioned in the other parts of your position paper.

Suggestions for Instruction

Case Studies

Using case studies has the advantage of giving students a high degree of specificity and structure, while allowing them considerable input.

To develop or choose case studies that draw students into assignments and make them feel they are involved in authentic, relevant situations, teachers may find the following suggestions helpful:

- Ensure that each assignment is *relevant*. Students should feel that it is a typical, realistic example of a situation they may conceivably encounter after they graduate.
- Clearly *establish the purpose* of the assignment. Never let students feel that an assignment is of a "make work" nature.
- Ensure that the background is developed thoroughly, so that students will have a solid "feel" for the situation.
- *Make students work*. Rather than presenting students with information that they can simply regurgitate, let them tussle with numbers, research facts, and reach a decision.
- Add a touch of drama. *Create interest* by choosing or writing assignments that read like a short story. Introduce a human element, so that students can relate to the people they have to write about or from whom they supposedly drew information.
- Whenever possible, *use dialogue* or choose case studies that contain dialogue rather than simple narrative descriptions. Students can too easily copy segments of narrative, but cannot readily copy dialogue. Dialogue is more difficult to write, and takes more space on the assignment page, but it forces students to search for and extract relevant facts.

Online Resources for Case Studies

The following websites present case studies or ideas for developing case studies.

Access Excellence @ the National Health Museum Activities Exchange. Access Excellence Activities Collection: <http://www.accessexcellence.org/AE/index.html>

This website contains an extensive archive of student activities connected to the life and physical sciences. There is something for just about everyone here if one is willing to browse the many links available.

Cal State Fullerton. Physics 301—Energy and the Environment. Energy and Environment Cases: <http://energy.fullerton.edu/case-ideas.html>

This website features five case studies related to energy sources and the environment. These range from the prospect of electric-only vehicles to global climate change, to coal power versus nuclear generation. The website has a physics/engineering focus.

ETHEX (Exploratorium's Ethical Scenarios Forum). Diving into the Gene Pool: <http://www.exploratorium.edu/genepool/ETHEX.html>

This website offers teachers three case study scenarios dealing with science ethics, primarily in the areas of genetic testing, genetically modified foods, and possible improprieties in the use of information related to genetic manipulation.

Kennesaw State University. ChemCases: Decision Making and Technology: <http://science.kennesaw.edu/~mhermes/chem.htm>

This website consists of a series of curriculum supplement cases to be used in teaching a general chemistry course with a science/engineering focus. Each case study features foundational principles typically addressed in a traditional general chemistry curriculum. These cases then address the decision making that influences development of new consumer, agricultural, and pharmaceutical products. The cases provide students with opportunities to flex the components of the STSE decision-making process in the Manitoba curriculum.

The McGraw-Hill Companies. General and Human

Suggestions for Instruction

Biology. Bioethics Case Studies: <http://www.mhhe.com/biosci/genbio/olc_linkedcontent/bioethics_cases/>

This website links to a large number of different case studies developed for courses that relate to human biology. Among these are links to stem-cell research, artificial *in utero* techniques, embryo research, sports issues, HIV/AIDS, osteoporosis, and many other areas.

National Center for Case Study Teaching in Science. Case Method Teaching: <http://ublib.buffalo.edu/libraries/projects/cases/teaching/novel.html>

James B. Conant of Harvard University was among the first science educators to use historical case studies in his teaching as a means of connecting science content *contextually*. For teachers interested in problem-based learning (PBL) techniques, this website is a veritable mine of information and analysis of the case-study teaching and learning style.

SCOPE (Science Controversies On-line Partnerships in Education). Genetically Modified Food: <http://scope.educ.washington.edu/gmfood/>

The advent of genetically modified (GM) foods in the human food chain at the grocery store has resulted in much public debate, scientific discussion, and coverage in various communication media. This website offers FAQ pages and web links to the issue of genetically modified organisms (GMOs) in our food supply.

University at Buffalo. The National Center for Case Study Teaching in Science Case Collection: <http://ublib.buffalo.edu/libraries/projects/cases/ubcase.htm>

This website provides numerous examples of science case studies developed by teachers for teachers. Copyright for most of these cases is held by the National Center for Case Study Teaching in Science. This body encourages educational, not-for-profit use of their cases by individual instructors. If teachers plan to use the cases from this website in their classrooms on this basis, they do not need to contact the National Center for Case Study Teaching in Science for permission. However, reproduction of any case in the collection in a printed work (such as a course-pack) or republication onto a website requires permission. Teachers will need to *register* with a valid email address to obtain a password for entry and downloading. The opportunity to submit cases to this organization for upload to the website also exists.

University of Delaware. Problem-Based Learning (PBL) Clearinghouse: <https://chico.nss.udel.edu/Pbl/index.jsp>

This website, which requires teachers to generate a user name and a password, directs its energies toward a problem-based learning (PBL) model that has gained credence in recent years among educators. The PBL Clearinghouse offers a collection of problems and articles to assist educators in using problem-based learning. The problems and articles are reviewed by experts in the science content areas. Teaching notes and supplemental materials accompany each problem, providing innovative and classroom-tested insights and strategies. Access to the Clearinghouse collection is limited to educators who *register via an online application*, but the materials are free, and no obligation exists beyond the fair classroom use of these materials.

Suggestions for Assessment

Role-Play

Use a presentation rubric for the role-playing activities. Peer-assessment could be used for evaluating the activities. Criteria should be developed with students and should include both content and presentation components such as the following:

- Position is clearly stated.
- Evidence is presented to support arguments.
- Answers to questions are clear and aligned with the position of the stakeholder.
- Presentation is clear and organized.
- Position of stakeholder is accurately represented.
- Personal biases are absent.
- Language and attitude are appropriate.

Debates

- Use a rubric for assessing the debate. A suggested rubric can be found below.
- Students peer-assess the debating skills of their classmates using criteria that were developed in advance with students.

Position Paper

Use a rubric for assessing the position paper. Criteria for the activity should be developed with students and could include components such as the following:

- Position is clearly stated.
- An understanding of the scientific knowledge surrounding the issue is evident.
- Evidence is presented to support arguments.
- Opposing claims are presented along with evidence to support them.
- Reasons are given for not agreeing with opposing claims.
- Paper is well organized and clearly demonstrates an understanding of the issue.
- Data and others' work are clearly referenced.
- References are written in the correct format.

Students can be asked to present their position to the class. A presentation rubric can be used to assess this work.

Debating Rubric

Criteria	Exemplary 4	Accomplished 3	Developing 2	Beginning 1
Organization of Opening Statement	Always maintains focus on the topic.	Usually maintains focus on the topic.	Sometimes maintains focus on the topic.	Does not maintain focus on the topic.
Use of Evidence to Support Claims	Always uses evidence to support claims.	Usually uses evidence to support claims.	Sometimes uses evidence to support claims.	Does not use evidence to support claims.
Persuasiveness	Arguments are clear and convincing.	Arguments are usually clear and convincing.	Arguments are sometimes clear and convincing.	Arguments are not clear and not convincing.
Teamwork	Always uses team members equally effectively.	Usually uses team members equally effectively.	Sometimes uses team members equally effectively.	Does not use team members equally effectively.
Organization of Closing Statement	Always responds with points that are specific to the topic.	Usually responds with points that are specific to the topic.	Sometimes responds with points that are specific to the topic.	Does not respond with points that are specific to the topic.

Suggestions for Assessment

Case Studies

Brainstorm with students to determine what criteria should be used to evaluate responses to questions in a case study. Criteria could include the following:

- Response clearly answers the question.
- Response uses evidence to identify issues referred to in the question.
- Response justifies suggested course of action using evidence.

Rubrics/Checklists

- Developing Assessment Rubrics in Science (see Appendix 8)
- Assessment Rubrics (see Appendix 9)

Journal Writing

- Journal Writing and Assessment (*SYSTH* 13.21)
- Reflection on debate (What surprising points were raised during the debate? Do you think there is a right or wrong answer? What valid facts were used to support the arguments? Summarize the arguments given by each team.)
- Word Cycle (*SYSTH* 10.21)

Performance Assessment/Collaboration

The focus for assessment of skill-related learning experiences can be on performance and collaboration, as well as the understanding demonstrated by the student’s ability to relate observations to their knowledge base. The teacher should specify, in advance, what the focus will be.

For instance, if students were asked to demonstrate their understanding of movement of substances across a cell membrane, the following items could be useful:

- Provide *unlabelled* diagrams of active transport diffusion and osmosis. Students identify what each represents and explain what is happening.
- Compare and contrast passive and active transport.
- Draw a Concept Map to illustrate how materials move in and out of a cell.
- Explain why the ability to regulate the movement of materials into and out of the cell is important. (In their response, students should refer to life processes and the concept of homeostasis.)

Pencil-and-Paper Tasks

- Word Cycle (*SYSTH* 10.21)
- Compare and Contrast (*SYSTH* 10.24)
- Concept Relationship Frame (*SYSTH* 11.20, 11.35)
- Fact-Based or Issue-Based Article Analysis (*SYSTH* 11.40, 11.41)

Teacher Notes