TOPIC 4: SOLUTIONS

Topic 4: Solutions

C11-4-01 Describe and give examples of various types of solutions.
Include: all nine possible types

C11-4-02 Describe the structure of water in terms of electronegativity and the polarity of its chemical bonds.

C11-4-03 Explain the solution process of simple ionic and covalent compounds, using visual, particulate representations and chemical equations.
Include: crystal structure, dissociation, hydration

C11-4-04 Explain heat of solution with reference to specific applications.
Examples: cold packs, hot packs…

C11-4-05 Perform a lab to illustrate the formation of solutions in terms of the polar and non-polar nature of substances.
Include: soluble, insoluble, miscible, immiscible

C11-4-06 Construct, from experimental data, a solubility curve of a pure substance in water.

C11-4-07 Differentiate among saturated, unsaturated, and supersaturated solutions.

C11-4-08 Use a graph of solubility data to solve problems.

C11-4-09 Explain how a change in temperature affects the solubility of gases.

C11-4-10 Explain how a change in pressure affects the solubility of gases.

C11-4-11 Perform a lab to demonstrate freezing-point depression and boiling-point elevation.

C11-4-12 Explain freezing-point depression and boiling-point elevation at the molecular level.
Examples: antifreeze, road salt…

C11-4-13 Differentiate among, and give examples of, the use of various representations of concentration.
Include: grams per litre (g/L), % weight-weight (% w/w), % weight-volume (% w/v), % volume/volume (% v/v), parts per million (ppm), parts per billion (ppb), moles per litre (mol/L) (molarity)

C11-4-14 Solve problems involving calculation for concentration, moles, mass, and volume.

C11-4-15 Prepare a solution, given the amount of solute (in grams) and the volume of solution (in millilitres), and determine the concentration in moles/litre.

C11-4-16 Solve problems involving the dilution of solutions.
Include: dilution of stock solutions, mixing common solutions with different volumes and concentrations

C11-4-17 Perform a dilution from a solution of known concentration.

C11-4-18 Describe examples of situations where solutions of known concentration are important.
Examples: pharmaceutical preparations, administration of drugs, aquaria, swimming-pool disinfectants, gas mixes for scuba, radiator antifreeze…

C11-4-19 Describe the process of treating a water supply, identifying the allowable concentrations of metallic and organic species in water suitable for consumption.

Suggested Time: 18.0 hours

SPECIFIC LEARNING OUTCOME

C11-4-01: Describe and give examples of various types of solutions.
Include: all nine possible types

(1.0 hour)

SLO: C11-4-01

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In Grade 7 Science, students investigated the characteristics of, and relationships among, solutions and mixtures, including

- differentiating between pure substances and mixtures and solutions versus mechanical mixtures (learning outcomes 7-2-13 and 7-2-14)
- demonstrating separation techniques for solutions (e.g. evaporation and introductory filtration) and mechanical mixtures (learning outcome 7-2-18)

Grade 7 Science included a discussion of the characteristics of solutions, with examples from daily life, and a discussion of solutions in terms of the particle theory of matter.

Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

Demonstration/Discrepant Event

A demonstration that is often called "the impossible transfer trick" is an effective way to introduce the topic of solutions. Prepare about 50 mL of a supersaturated solution of sodium acetate, NaAc, in a new 100 mL Erlenmeyer flask. If an older, dirty flask is used, the solution will likely precipitate prematurely. If it does precipitate, the solution can be gently warmed in a hot water bath to redissolve the NaAc. Once the nearly hot solution is saturated, allow the solution to cool slowly to room temperature. Wipe the mouth of the flask carefully with a damp towel to remove any traces of NaAc. Place a similar 100 mL flask with an equal volume of water in it next to the NaAc flask. Ask students whether it is possible for them to pour all the water into a 25 mL beaker. Have a student try it, with obvious results. Now claim that students can do it without spilling a drop. Use a clean beaker, but

General Learning Outcome Connections

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

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

GLO D5: Understand the composition of the Earth's atmosphere, hydrosphere, and lithosphere, as well as the processes involved within and among them.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-R1: Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

with a small crystal seed placed at the bottom. The crystal solid that results will form a tall column in the beaker if poured slowly. The column is fragile.

TEACHER NOTES

Most chemical reactions occur in an aqueous medium, and not in the solid, liquid, or gaseous phase. Students should be familiar with the nine types of solutions presented below and should be able to provide an example for each. Emphasize that the smaller amount in a solution is usually classified as the *solute* and the larger amount the *solvent*. Ask students to provide examples other than those presented below.

Types of Solutions

Solution	Example
solid in solid	• copper in silver (sterling silver) • zinc in copper (brass)
solid in liquid	• salt in water (ocean water) • iodine in alcohol (tincture)
solid in gas	• microscopic particulates in air • mothball particles in air
liquid in solid	• mercury in silver amalgams (tooth fillings)*
liquid in liquid	• ethylene glycol in water (engine antifreeze) • methanol in water (gas line antifreeze)
liquid in gas	• water vapour in air
gas in solid	• hydrogen in palladium** (purification of hydrogen) • poisonous gases *adsorbed* in carbon (charcoal filter)
gas in liquid	• carbon dioxide in beverages (carbonated beverages) • oxygen in water (supporting aquatic life)
gas in gas	• oxygen in nitrogen (air)

* Have students ask their dentists to explain the use of a known carcinogen in an amalgam for oral/dental use.
** At room temperature, palladium will absorb 900 times its own volume of hydrogen.

Journal Writing

Have students relate the demonstration/discrepant event in their journals. Students could also include their dentists' explanation of the use of a known carcinogen in an amalgam for oral/dental use (as a follow-up).

SPECIFIC LEARNING OUTCOME

C11-4-01: Describe and give examples of various types of solutions.
Include: all nine possible types

(continued)

SUGGESTIONS FOR ASSESSMENT

Visual Display

Students could create a visual display in their notebooks or on poster paper to represent the nine types of solutions and examples. Have them indicate where the examples could be found in their daily lives. They could also bring examples of solutions from home.

Research Reports

Have students brainstorm additional examples of solutions. Students could research the examples and report their findings either individually or in small groups. The information collected could be presented as

- written reports
- oral presentations
- bulletin board displays

Each of these presentation styles could be assessed using an appropriate rubric created with students prior to the assignment. Samples of presentation rubrics are provided in Appendix 10 of this document.

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Paper-and-Pencil Tasks: Written Test/Quiz

Students demonstrate an understanding of the types of solutions and provide alternate examples.

LEARNING RESOURCES LINKS

Chemistry (Chang 488)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 454)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 238)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 285)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 266)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 503)

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-R1: Synthesize information obtained from a variety of sources.

Include: print and electronic sources, specialists, other resource people

NOTES

SPECIFIC LEARNING OUTCOME

C11-4-02: Describe the structure of water in terms of electronegativity and the polarity of its chemical bonds.

(0.5 hour)

SLO: C11-4-02

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In Grade 10 Science, students constructed Bohr or Electron (Lewis) Dot models of a variety of compounds containing ionic and covalent compounds. The Bohr models were constructed up to and including atomic number 18 (argon). Examples may also have included ammonia, methane, and water. (See *Senior 1 Science: A Foundation for Implementation* Appendix 2.6, 2.7, and *Senior 2 Science: A Foundation for Implementation*, Appendix 2.1.)

TEACHER NOTES

Introducing the concept of *electronegativity* at this point will enable teachers to explain the solution process more clearly in the next learning outcome (C11-4-03), which deals specifically with the polarity of the water molecule as it relates to the solution process. A detailed explanation of *polar covalent bonding* is not expected at this time. This extension will be discussed in Grade 12 Chemistry.

Demonstration

Introduce polarity with a demonstration illustrating that a stream of water can be bent by either a magnetic or an electric force. For example, use of a burette and a source of static electricity works well. The stronger the electrostatic force used, the thinner the stream will be and the more dramatic the effect will be. Use this demonstration to generate class discussion about the shape of the water molecule and its polarity. Most student learning resources will include this as a teacher demonstration. Much discussion should follow. Encourage students to justify their speculations based on their own emerging models of electrostatics that began with Grade 3 Science and were last addressed in Grade 9 Science.

The demonstration also leads to the concept of *electronegativity*, which is a measure of the ability of an atom in a chemical bond to attract electrons. In the case of the water molecule, the oxygen atom is more electronegative than hydrogen is. As a result, the electrons in the chemical bonds orient themselves more completely around the oxygen atom. This makes the hydrogen more positive and the oxygen more negative. This results in polar bonds and a polar molecule.

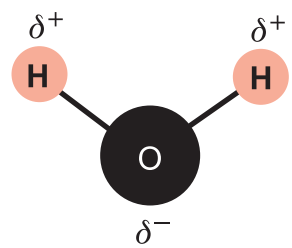
General Learning Outcome Connections

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-R1: Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people



Polar Water Molecule

Show students a periodic table with electronegativity values to explain the polarity of the atoms in the water molecule.

The demonstration could be done either by two students or by the whole class if enough equipment is available. Static electricity equipment would most likely be found in the school lab facility. Some faucets in chemistry labs (e.g., those with narrowed spouts) can produce streams thin enough that the whole class could (and should) get involved in the demonstration.

SUGGESTIONS FOR ASSESSMENT

Assessment for understanding of electronegativity and the polarity of chemical bonds will occur later when students are expected to explain the solution process.

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Visual Displays

Students could represent the diagram of a polar water molecule using

- posters
- models
- multimedia

Each of these presentation styles could be assessed using an appropriate rubric created with students prior to the assignment. Samples of presentation rubrics are provided in Appendix 10 of this document.

SPECIFIC LEARNING OUTCOME

C11-4-02: Describe the structure of water in terms of electronegativity and the polarity of its chemical bonds.

(continued)

Journal Writing

Students may want to describe the demonstration and its significance in their journals.

Paper-and-Pencil Tasks

Students should be able to explain why a molecule such as water is polar, based on the electronegativity of a similar molecule such as H_2S.

LEARNING RESOURCES LINKS

Chemistry (Chang 357)

Chemistry (Zumdahl and Zumdahl 352)

Chemistry: The Central Science (Brown, *et al.* 285)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 303, 311)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 134)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 168, 263)

Introductory Chemistry: A Foundation (Zumdahl 319)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 176, 245)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 86, 91)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 274)

Nelson Chemistry 12, Ontario Edition (van Kessel, *et al.* 252)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 200, 272)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 184, 261, 514)

Most of the resources listed here are quite complex and move quickly into molecular geometry.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-R1: Synthesize information obtained from a variety of sources.

Include: print and electronic sources, specialists, other resource people

NOTES

SPECIFIC LEARNING OUTCOME

C11-4-03: Explain the solution process of simple ionic and covalent compounds, using visual, particulate representations and chemical equations.

Include: crystal structure, dissociation, hydration

(1.0 hour)

SLO: C11-4-03

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In Grade 10 Science (learning outcome S2-2-02), students explained, through use of the periodic table, how and why elements combine in specific ratios to form ionic and covalent compounds. They also constructed Bohr and Electron Dot models of these types of compounds and learned how to name and write their formulas.

In Grade 11 Chemistry (learning outcome C11-1-03), students were introduced to crystals and crystal lattice structures. They were also asked to draw diagrams of crystals.

Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

TEACHER NOTES

Teachers may want to combine learning outcome C11-4-03 with the next learning outcome (C11-4-04), which addresses *heat of solution*.

The Solvation Process

A sodium chloride crystal, NaCl, will be used in the following explanation of the solvation process with students. Encourage students to explain the phenomena involved using other examples once they understand the behaviour of NaCl.

A detailed explanation of the solvation process is complex and is beyond the scope of Grade 11 Chemistry. There are many intermolecular forces that interact: solvent-solvent, solute-solute, and solute-solvent particles. Depending on the characteristics of the solute and the solvent, each of these interactions may be either exothermic or endothermic. Another factor involved in the "mix" is that of *randomness*. According

General Learning Outcome Connections

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

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

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

Skills and Attitudes Outcomes

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-R1: Synthesize information obtained from a variety of sources.

Include: print and electronic sources, specialists, other resource people

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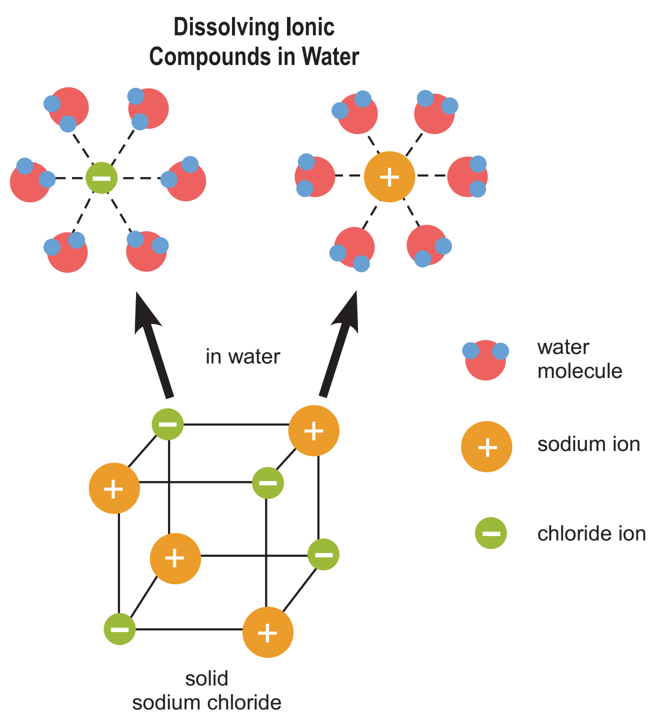
to thermodynamic principles, matter tends to become more random. As a result of the interaction of these factors, the solubility of a solute can vary significantly with each solvent. The saying that "like dissolves like" is helpful in predicting the solubility of a substance in a given solvent. What this means is that two substances with similar polarity are most likely to be mutually soluble. If a solute and solvent are mutually soluble in all proportions they are both said to be *miscible*.

Students are aware (from learning outcome C11-4-02) that water molecules are polar and have a partial positive charge around the hydrogen atoms and a partial negative charge around the oxygen atom.

When a solute is placed into a solvent, the solvent particles completely surround the surface of the solute particles. As shown in the diagram below, for the case of water and NaCl, the polar water molecules orientate themselves around each exposed ion on the crystal surface (lattice) of the solid. The positive end of the water molecule orientates itself toward the negative chloride ion Cl^- and the negative end of the water molecule toward the positive sodium ion Na^+.



SPECIFIC LEARNING OUTCOME

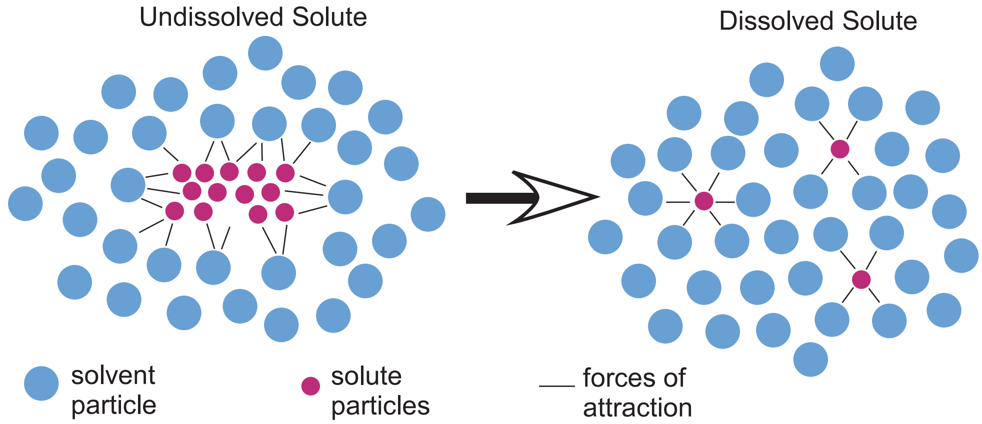
C11-4-03: Explain the solution process of simple ionic and covalent compounds, using visual, particulate representations and chemical equations.

Include: crystal structure, dissociation, hydration

(continued)

An electrostatic competition occurs between the water molecules and the forces of attraction within the solute crystal. If the solute is soluble, the attraction between the solvent molecules and the solute ions gradually increases to the point where it finally exceeds the forces holding the ions into the crystal lattice. As a result, the solute ions are pulled into the solvent and become completely surrounded by the solvent molecules. (The diagram below demonstrates the concept of *solvation*).

Solvation



The separation of ions is called *dissociation*, whereas the process of surrounding the solute particles with solvent particles is called *solvation*. If the solvent is water, this process is called *hydration*. The solute particles are said to be hydrated.

Covalent Solvation

Students need to be aware that an entire molecule is pulled away from the solid structure in a covalent solid as it goes into solution.

Chemical Equations

$$NaCl_{(s)} \xrightarrow{H_2O_{(l)}} Na^{+}_{(aq)} + Cl^{-}_{(aq)}$$

$$C_{12}H_{22}O_{11(s)} \xrightarrow{H_2O_{(l)}} C_{12}H_{22}O_{11(aq)}$$

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-R1: Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

Extension

A number of properties are associated with water of hydration.

- *Decrepitation* is the process by which the water of hydration that is mechanically bound to the crystal lattice is vigorously released from some crystals when heated (e.g., lead nitrate).
- *Efflorescence* is the process by which loosely held water of hydration is lost when the crystals are exposed to the air (e.g., $Na_2CO_3 \cdot 10H_2O$).

SUGGESTIONS FOR ASSESSMENT

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Visual Displays

Students could represent what they have learned using

- posters
- pamphlets
- bulletin board displays
- models

Each of the visual displays could be assessed using an appropriate rubric created with students prior to the assignment. Samples of presentation rubrics are provided in Appendix 10 of this document.

Specific Learning Outcome

C11-4-03: Explain the solution process of simple ionic and covalent compounds, using visual, particulate representations and chemical equations.

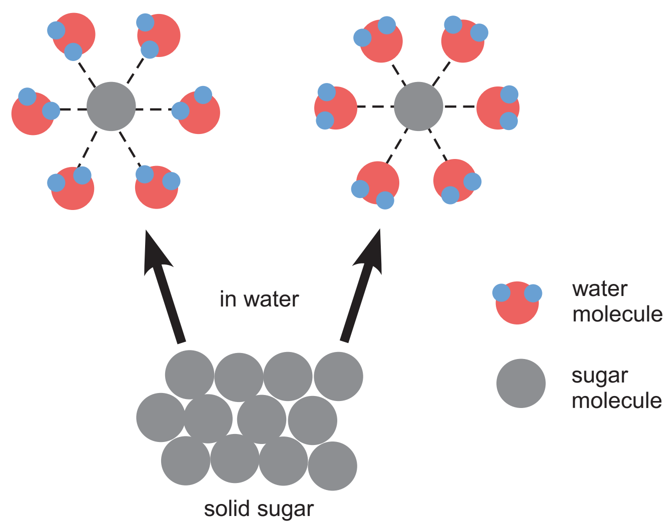
Include: crystal structure, dissociation, hydration

(continued)

Paper-and-Pencil Tasks

1. Students should be able to use diagrams, such as the one that follows involving the *molecular compound* crystalline sugar, to explain the solvation process of either an ionic or a molecular solid dissolved in water.

Dissolving Molecular Compounds in Water



2. Use a Knowledge Chart to summarize the solution process for ionic compounds. (See *SYSTH* 9.8–9.9, 9.24–9.25.)

3. Students could create a song, skit, poem, comic strip, or pantomime to illustrate the solution process.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-R1: Synthesize information obtained from a variety of sources.

Include: print and electronic sources, specialists, other resource people

LEARNING RESOURCES LINKS

Chemistry (Chang 117, 489)

Chemistry: The Central Science (Brown, *et al.* 487)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 452)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 135)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 455)

Introductory Chemistry: A Foundation (Zumdahl 424)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 246)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 239)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 273)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 512)

SPECIFIC LEARNING OUTCOME

C11-4-04: Explain heat of solution with reference to specific applications.

Examples: cold packs, hot packs…

(0.5 hour)

SLO: C11-4-04

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In Grade 7 Science (learning outcomes 7-2-16 to 7-2-20), students explored some properties of solutions. Although they investigated the solution process, they did not discuss the difference between exothermic and endothermic dissolving reactions. There was, however, some introductory treatment of the differences between *temperature* and *heat* (learning outcome 7-2-07).

Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

TEACHER NOTES

Teachers will most likely treat learning outcomes C11-4-04 and C11-4-03 together.

When attractive forces are broken, energy is required. Therefore, the separation of solute particles from one another and the separation of solvent particles from one another are both endothermic processes. The attraction between solute and solvent particles during the solvation process is exothermic. Whether energy is absorbed or released in the overall net process of solution formation depends on the balance between these two processes. The net energy change is called the *heat of solution*.

If the amount of energy absorbed is greater than the amount of energy released, then the overall solution becomes *endothermic*.

Example: $NH_4NO_{3(s)} + \text{heat} = NH_4{}^+{}_{(aq)} + NO_3{}^-{}_{(aq)}$

General Learning Outcome Connections

GLO A5: Recognize that science and technology interact with and advance one another.

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

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

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

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

If the amount of energy absorbed is less than the amount of energy released, then the overall solution becomes *exothermic*.

Example: $CaCl_{2(s)} = Ca_2{}^{+}{}_{(aq)} + 2Cl^{-}{}_{(aq)}$ + heat

Demonstration

Teachers are reminded to select an activity, demonstration, or lab investigation that is appropriate for students and for the science facility available.

1. Add a small amount of calcium chloride, $CaCl_2$, and ammonium nitrate, NH_4NO_3, to separate test tubes. Half fill each test tube with water at room temperature. Then, with gentle agitation, observe the temperature change for each, as felt through the glass wall of the test tube (these changes are detectable but do not present risk factors). Ammonium nitrate is *endothermic* when it dissolves in water, whereas calcium chloride is *exothermic*. These are the usual substances found in cold and hot packs respectively.
2. This demonstration requires some preparation but it is well worth the effort. You can solidly freeze a beaker to a 40 cm^2 sheet of ¼ inch (0.5 cm) plywood!
   - First, spray about 5 mL of water onto the centre of the plywood. This can be done before students enter the room.
   - With the plywood on a table, place the 400 mL beaker on the puddle of water. Add 20 g of barium hydroxide, $Ba(OH)_2 \cdot 8H_2O$, and then 10 g of ammonium thiocyanate, NH_4SCN.
   - Mix with a long stirring rod for about two minutes until the mixture starts to become liquefied.
   - Try to lift the beaker. It will be frozen to the plywood.

   Caution: Ammonia is produced as a product and so a well-ventilated area is required. The beaker should be placed in the fume hood once the demonstration is finished. Other compounds will also produce an endothermic reaction, and are referenced in the Learning Resources Links.

SPECIFIC LEARNING OUTCOME

C11-4-04: Explain heat of solution with reference to specific applications.

Examples: cold packs, hot packs…

(continued)

SUGGESTIONS FOR ASSESSMENT

Laboratory/Demonstration Reports

The lab activities suggested for this learning outcome could be assessed as formal lab reports using the Laboratory Report Outline or the Laboratory Report Format (see *SYSTH* 11.38, 14.12) or by using questions and answers from the data collected from the activities.

Journal Writing

If the plywood demonstration is done, students may want to elaborate on it in their journals.

Paper-and-Pencil Tasks

Students should be able to explain the interaction of particles on a molecular level and explain how the interaction is related to the absorption or release of energy.

LEARNING RESOURCES LINKS

Chemistry (Chang 489)

Chemistry (Zumdahl and Zumdahl 515)

Chemistry: The Central Science (Brown, *et al.* 487)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 494)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 457)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 291)

Skills and Attitudes Outcomes

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

Notes

SPECIFIC LEARNING OUTCOME

C11-4-05: Perform a lab to illustrate the formation of solutions in terms of the polar and non-polar nature of substances.

Include: soluble, insoluble, miscible, immiscible

(1.5 hours)

SLO: C11-4-05

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

The definition of solubility and the factors affecting solubility are introduced in Grade 7 Science in the form of an experiment (learning outcome 7-2-20 included terms such as agitation, surface area, particle size, and temperature). However, the concept of polar and non-polar molecules is new to students at this level.

Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

TEACHER NOTES

Most chemistry texts provide information and activities that discuss the terms *soluble*, *insoluble*, *miscible*, and *immiscible*.

Several demonstrations and lab activities are suggested for this learning outcome. As an alternative to informing students that "like dissolves like," students could do a lab in which they discover this for themselves.

Laboratory Activity

Have students do a lab activity to discover the relationship between polar and non-polar substances. See Appendix 4.1: Polar and Non-Polar Substances.

Students mix each of the following substances with every other substance: copper(II) sulphate ($CuSO_4$), water, vinegar, iodine, vegetable oil, and kerosene. Related terms (e.g., soluble, insoluble, miscible, immiscible) will be operationally defined through discovery during the lab.

General Learning Outcome Connections

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

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

GLO C2: Demonstrate appropriate scientific inquiry skills when seeking answers to questions.

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

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C11-0-S1: Demonstrate work habits that ensure personal safety and the safety of others, as well as consideration for the environment.

Include: knowledge and use of relevant safety precautions, Workplace Hazardous Materials Information System (WHMIS), emergency equipment

C11-0-S4: Select and use scientific equipment appropriately and safely.

Examples: volumetric glassware, balance, thermometer…

C11-0-S5: Collect, record, organize, and display data using an appropriate format.

Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…

Demonstrations

Select the demonstration that best suits the class and available equipment. With supervision, students could easily complete demonstrations such as the following.

1. **Water and Oil:** Use demonstrations to help students develop an understanding of the molecular interactions between polar and non-polar molecules. For overhead-transparency demonstrations that simulate the mixing of like and unlike molecules of solute and solvent, see Appendix 4.2: Why Don't Water and Oil Mix?
2. **The "Polar" Disk:** Use a soft pencil to shade a piece of paper as densely as possible. Use a standard hole puncher to make approximately 20 disks from this paper. Add 100 mL of trichlorotrifluoroethane (TTE) to a 250 mL flask, together with an equal volume of water. Place the small paper disks into the flask containing the two liquids. Securely stopper the flask and shake. When the flask is shaken, the disks always orient themselves with the black side down.
3. **Immiscible Liquids:** The following solution illustrates immiscible liquids. Half fill a 1 L clear plastic bottle with water, followed by 50 mL of ethanol. Then fill the bottle to the top with paint thinner. Add a few drops of blue food colouring and cap the bottle. Slowly rock the bottle and watch the immiscible fluids form waves.

SUGGESTIONS FOR ASSESSMENT

Demonstration/Laboratory Reports

The activities suggested for this learning outcome could be assessed as formal lab reports using the Laboratory Report Outline or the Laboratory Report Format (see *SYSTH* 11.38, 14.12) or by using questions and answers from the data collected from the activities.

Journal Writing

Students may wish to describe interesting applications to the demonstrations in their journals.

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

SPECIFIC LEARNING OUTCOME

C11-4-05: Perform a lab to illustrate the formation of solutions in terms of the polar and non-polar nature of substances.

Include: soluble, insoluble, miscible, immiscible

(continued)

Paper-and-Pencil Tasks

Students are expected to explain the difference between polar and non-polar substances.

LEARNING RESOURCES LINKS

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 330)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 264, 454)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 244)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 292)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 274—Investigation 6.2.1)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 514, 515)

The references given here are for polar, non-polar, miscible, and immiscible substances.

Skills and Attitudes Outcomes

C11-0-S1: Demonstrate work habits that ensure personal safety and the safety of others, as well as consideration for the environment.

Include: knowledge and use of relevant safety precautions, Workplace Hazardous Materials Information System (WHMIS), emergency equipment

C11-0-S4: Select and use scientific equipment appropriately and safely.

Examples: volumetric glassware, balance, thermometer…

C11-0-S5: Collect, record, organize, and display data using an appropriate format.

Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…

Notes

SPECIFIC LEARNING OUTCOME

C11-4-06: Construct, from experimental data, a solubility curve of a pure substance in water.

(1.0 hour)

SLO: C11-4-06

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In Grade 7 Science (learning outcome 7-2-22), students were introduced to the terms *saturated* and *unsaturated*. During the discussion, students will have been introduced to the concept that temperature affects the amount of solid that can be dissolved in a given solvent.

In Grade 11 Chemistry (learning outcome C11-4-04), students were introduced to the *heat of solution* concept, and were informed that the solution process could be either exothermic or endothermic, depending on the solute and the solvent.

Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

TEACHER NOTES

Point out to students that, for certain solids, the amount of solid that dissolves at a given temperature actually decreases as the temperature increases.

Some chemistry resources (e.g., Mustoe, *et al.* 301) show a solubility graph that illustrates this counterintuitive reversal or "anomaly"; that is, for some solids, solubility decreases as temperature increases. A sample solubility graph that includes cerium sulphate, $Ce_2(SO_4)_3$, follows.

General Learning Outcome Connections

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

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

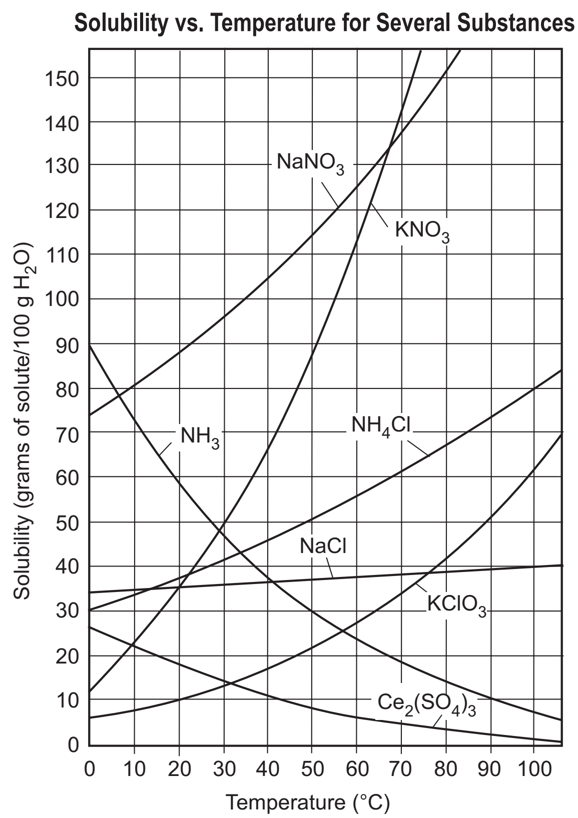
GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

C11-0-S8: Evaluate data and data-collection methods for accuracy and precision.
Include: discrepancies in data, sources of error, percent error

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction



Laboratory Activities

1. Most chemistry texts provide at least one lab activity to determine the solubility of an ionic salt. Text references can be found in the Learning Resources Links for this outcome. There is also a microscale chemistry lab that can be done to examine the solubility behaviour of potassium nitrate, KNO_3.
2. The lab outlined in Appendix 4.3: Constructing a Solubility Curve asks students to construct a solubility curve for ammonium chloride, NH_4Cl. Rather than having every student doing all points on the solubility curve, teachers could give each lab group a specific amount of solute to be dissolved in water to produce a given amount of solution. Student groups then perform the lab to determine one of the points on a solubility curve for the given solid. Data is shared with the class to generate the complete solubility curve.

SPECIFIC LEARNING OUTCOME

C11-4-06: Construct, from experimental data, a solubility curve of a pure substance in water.

(continued)

3. If teachers have access to a calculator-based laboratory (CBL) system or temperature probes, they could have students do a lab activity to determine a complete solubility curve for a given solute species.

SUGGESTIONS FOR ASSESSMENT

Laboratory Reports

Assess student lab reports and performance during the lab activity using the Laboratory Report Outline (see *SYSTH* 11.38).

Journal Writing

Any journal reflections that students complete during or after a lab activity can help determine the ease with which they understand the lab directions. It is here that students can provide a personal interpretation of the events observed during a lab activity.

Paper-and-Pencil Tasks

Ask students to explain the type of solution that occurs when a sample is not on the solubility curve but below it or above it (i.e., saturated and unsaturated solutions). Students should also be able to use the solubility curve and other graphs to determine the solubility of amounts of solute dissolved in a given amount of solvent. The questions and discussion that occur during the treatment of learning outcome C11-4-06 will complement and introduce the following two learning outcomes (C11-4-07 and C11-4-08), which discuss saturated solutions and problem solving with solubility curves.

SKILLS AND ATTITUDES OUTCOMES

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

C11-0-S8: Evaluate data and data-collection methods for accuracy and precision.
Include: discrepancies in data, sources of error, percent error

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

LEARNING RESOURCES LINKS

Chemistry (Chang 495)

Chemistry (Zumdahl and Zumdahl 522)

Chemistry: The Central Science (Brown, *et al.* 497)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 459)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 498)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 457)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 249)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 295)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 314)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 515)

Investigations

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 458—the effect of temperature on solubility)

Glencoe Chemistry: Matter and Change: Laboratory Manual – Teacher Edition (113—making a solubility curve)

Glencoe Chemistry: Matter and Change: Small-Scale Laboratory Manual – Teacher Edition (41—the effect of temperature on solubility)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 296—plotting solubility curves)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 249—plotting solubility curves)

Microscale Chemistry Laboratory Manual (Slater and Rayner-Canham 29—solubility curves)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 314—solubility curve of a solid)

SPECIFIC LEARNING OUTCOME

C11-4-07: Differentiate among saturated, unsaturated, and supersaturated solutions.

(0.5 hour)

SLO: C11-4-07

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In Grade 7 Science (learning outcome 7-2-22), students were expected to differentiate between saturated and unsaturated solutions.

Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

TEACHER NOTES

The discussion before and after a previous lab (for learning outcome C11-4-05) may have included the use of the terms *saturated*, *unsaturated*, and *supersaturated*. Students may have observed *super cooling* during the experiment if stirring was not continuous and the cooling process was slow.

A discussion of the solubility curve that students have completed is an effective way to begin the discussion of the types of solutions that are possible.

- *Unsaturated solution*—a solution that holds less than the maximum amount of solute possible at a given temperature.
- *Saturated solution*—a solution that holds the maximum amount of solute possible at a given temperature.
- *Supersaturated solution*—a solution that holds more than the maximum amount of solute possible at a given temperature.

A supersaturated solution can be made by saturating a solution at a high temperature, and then cooling it very slowly. In this case, the solution holds more solute than it should at the temperature desired. These solutions tend to be rather

General Learning Outcome Connections

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

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

unstable and are easily disturbed from this state. Supersaturated solutions often precipitate prematurely for two reasons:

- The vessel is dirty and the contaminating particles act as a seed to initiate precipitation.
- The solution is cooled too rapidly.

It is possible for some solutions to be so supersaturated that even a slight jarring will cause rapid precipitation.

Demonstrations/Discrepant Events

1. In the treatment of learning outcome C11-4-01, students may have seen "the impossible transfer trick." The demonstration could be done again to reinforce the concept of supersaturation. Students can check the temperature of the solid sodium acetate and discover that it is quite high. The precipitation is exothermic.
2. A much simpler demonstration can be done with supersaturating a solution of sodium thiosulphate. If a microscopic slide projector is available in the biology lab at school, either of these supersaturated solutions (the sodium acetate solution or the sodium thiosulphate solution) could be poured into a petri dish that is already on the projector stage. If left to stand, the solution will precipitate and students will clearly be able to see the rapid growth and shape of the crystals.

Laboratory Activities

1. Have students distinguish between the three types of solutions by doing the lab activity outlined in Appendix 4.4: Unsaturated, Saturated, and Supersaturated Solutions.
2. In another lab activity, described in Appendix 4.5: Crystals and Crystal Growing, students use their knowledge from the previous lab to grow crystals. If possible, have all students grow crystals and have a competition to decide upon the purest and the largest crystal grown.

SPECIFIC LEARNING OUTCOME

C11-4-07: Differentiate among saturated, unsaturated, and supersaturated solutions.

(continued)

SUGGESTIONS FOR ASSESSMENT

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Paper-and-Pencil Tasks

Students could do an entry-level activity using a Compare and Contrast frame for unsaturated and saturated solutions (see *SYSTH* 10.24).

Laboratory Reports

The lab activities outlined for this learning outcome could be assessed by using questions and answers from the data collected from the various activities.

Demonstration

Students could be selected to demonstrate the supersaturation lab with either sodium thiosulphate or sodium acetate. Assessment could be done using a presentation rubric found in Appendix 10 of this document.

Journal Writing

Ask students to reflect on how they might use the discrepant event, “the impossible transfer trick,” in a magic show or how they could improve on the demonstration.

LEARNING RESOURCES LINKS

Chemistry (Chang 488)

Chemistry: The Central Science (Brown, *et al.* 491)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 458)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 498)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 265)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 512)

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.

Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

NOTES

SPECIFIC LEARNING OUTCOME

C11-4-08: Use a graph of solubility data to solve problems.

(1.5 hours)

SLO: C11-4-08

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students should have been familiarized with the term *grams of solute per 100 mL* from Grade 7 Science (learning outcome 7-2-21). They should also have an understanding of the terms *unsaturated*, *saturated*, and *supersaturated*. Some review will be necessary at this point.

TEACHER NOTES

There are three methods to saturate a solution:

- Add more solute.
- Decrease the temperature (for most solids).
- Evaporate the solvent.

Enrichment/Extension

Problems associated with evaporating the solvent can be more complex than the other two methods of saturating a solution. Such problems would be considered to be enrichment or an extension of this learning outcome.

Use a graph of solubility data that shows

- solids that have an increase in solubility with an increase in temperature
- solids that have a decrease in solubility with an increase in temperature

It may also be useful to include a gas on the graph, as the solubility of gases is discussed in learning outcome C11-4-09.

The following Sample Problems and Solutions are provided as a guide to using the solubility data from the sample solubility curve provided. For a full-page graph, see Appendix 4.6: Solubility Curve.

General Learning Outcome Connections

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

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

SKILLS AND ATTITUDES OUTCOMES

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

C11-0-S2: State a testable hypothesis or prediction based on background data or on observed events.

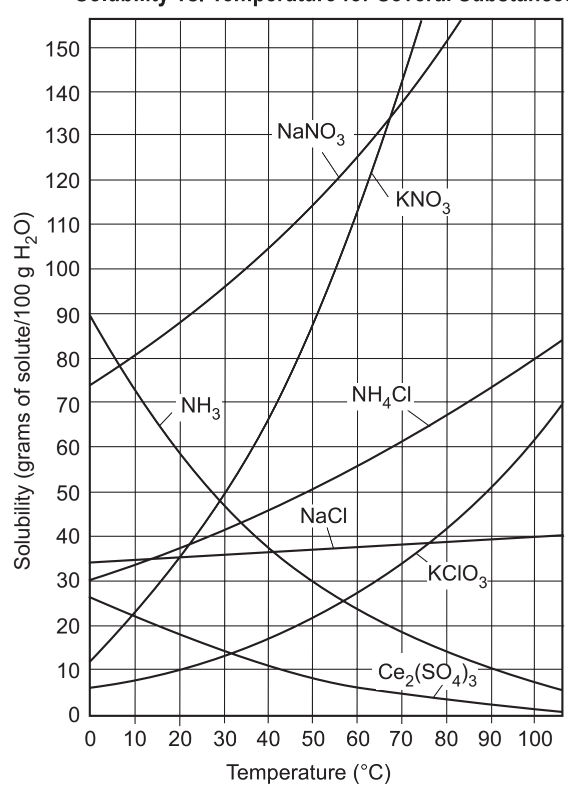
C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

C11-0-S8: Evaluate data and data-collection methods for accuracy and precision.

Include: discrepancies in data, sources of error, percent error

Sample Problems and Solutions

Solubility vs. Temperature for Several Substances



1. What is the solubility of potassium nitrate, KNO_3, at 44°C?

   Answer: 72 g of solute/100 g of water

2. 25 g of potassium nitrate is dissolved in 50 g of water at 30°C. Determine whether this solution is saturated. If yes, explain why.

   Answer: 25 g/50 g of water = 50 g/100 g of water

   If this value is transferred to the solubility curve graph, the point is exactly on the line, which means that the solution must be saturated at 30°C.

3. A solution contains 5.2 g of potassium nitrate, KNO_3, dissolved in 10 g of water at 40°C. What amount of KNO_3 would be required to saturate this solution?

   Answer: 5.2 g/10 g of water = 52 g/100 g of water

   This places the point on the solubility curve graph below the saturation curve. It would require 12 g/100 g of water to move the solution to the saturation line or 1.2 g/10 g of water.

SPECIFIC LEARNING OUTCOME

C11-4-08: Use a graph of solubility data to solve problems.

(continued)

4. A solution contains 33 g of KNO_3/30 g of water at 72°C. How much must this solution be cooled to saturate the solution?

   Answer: 33 g/30 g of water = 110 g/100 g of water

   If this data is transferred to the solubility curve graph, the point is to the right of the saturation curve. To saturate this solution, the temperature would need to be cooled 14°C to 58°C.

Laboratory Activity: Extension

Precipitation solution reactions are not part of Grade 11 Chemistry. However, now that students have a clear understanding to solubility, teachers could develop solubility rules as an extension activity with interested students.

SUGGESTIONS FOR ASSESSMENT

Verbal Explanations

Ask students to give verbal explanations in responding to questions related to solubility and unsaturated, saturated, and supersaturated solutions. These questions would be most logically answered if they related to a graph similar to the one provided in Appendix 4.6: Solubility Curve.

Paper-and-Pencil Tasks

Students should be able to solve problems that relate to the sample problems provided for learning outcome C11-4-08.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

C11-0-S2: State a testable hypothesis or prediction based on background data or on observed events.

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

C11-0-S8: Evaluate data and data-collection methods for accuracy and precision.

Include: discrepancies in data, sources of error, percent error

NOTES

SPECIFIC LEARNING OUTCOME

C11-4-09: Explain how a change in temperature affects the solubility of gases.

(0.5 hour)

SLO: C11-4-09

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

The solubility of gases in liquids has not been discussed in previous grades. In Grade 11 Chemistry, the physical properties of gases were addressed in learning outcome C11-2-01. These properties were explained using the Kinetic Molecular Theory (C11-1-02).

Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

TEACHER NOTES

To explain how a change in temperature affects the solubility of gases, teachers first need to review heat of solution (C11-4-04). The reason that the solubility of solids is so variable is that much of the energy for solvation is required to separate the solid particles from each other in the crystal lattice or from the molecular solid structure itself. This energy absorption is not required for a gas because all the particles are already separated. Consequently, the overall net process becomes exothermic, with the result that solubility is inversely proportional to temperature. The higher kinetic energy of gas particles allows them to escape from a solution more readily. As a result, the solubility of gases decreases with an increase in temperature.

More detailed explanations are available in the some of the chemistry texts referenced in the Learning Resource Links.

General Learning Outcome Connections

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

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

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

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

SKILLS AND ATTITUDES OUTCOMES

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

C11-0-D1: Identify and explore a current STSE issue.

Examples: clarify what the issue is, identify different viewpoints and/or stakeholders, research existing data/information…

C11-0-D2: Evaluate implications of possible alternatives or positions related to an STSE issue.

Examples: positive and negative consequences of a decision, strengths and weaknesses of a position…

Demonstration/Activity

In a demonstration/activity found in *Nelson Chemistry 11* (Jenkins, *et al.* 317), students are asked to make observations and answer questions about the release of air bubbles from water during warming.

STSE Issues

This learning outcome provides an opportunity for students to become more aware of STSE issues.

The relationship between the solubility of a gas and the temperature is important for oxygen-dependent aquatic life. When the organisms living in a stable aquatic environment are suddenly stressed by a change in the temperature of the water, their health may become compromised if they cannot move to a friendlier environment.

There are many instances where thermal pollution is becoming an environmental concern in the vicinity of power plants and large industrial complexes that use water for cooling.

STSE Decision-Making Issue

Have students research and examine local thermal contamination. Students review the pros and cons of the issue and then make decisions that relate to the environment.

Research Activity

Have students research local companies or industries that release thermal energy into the rivers and streams around them.

SPECIFIC LEARNING OUTCOME

C11-4-09: Explain how a change in temperature affects the solubility of gases.

(continued)

SUGGESTIONS FOR ASSESSMENT

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Research Reports

Have students research and report either individually or in small groups. The information collected could be presented as

- written reports
- oral presentations
- bulletin board displays
- multimedia presentations

Visual Displays

Students could present the material they have collected using

- posters
- pamphlets
- bulletin boards

Each of these presentation styles could be assessed using an appropriate rubric created with students prior to the assignment. Samples of presentation rubrics are provided in Appendix 10 of this document.

Activity Reports

The activities outlined for this leaning outcome could be assessed as formal lab reports using the Laboratory Report Outline or the Laboratory Report Format (see *SYSTH* 11.38, 14.12) or by using questions and answers from the data collected from the activities.

Journal Writing

Have students write a journal entry commenting on the extent of thermal pollution in their community. Is the concern connected to the economic development of the community?

SKILLS AND ATTITUDES OUTCOMES

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

C11-0-D1: Identify and explore a current STSE issue.

Examples: clarify what the issue is, identify different viewpoints and/or stakeholders, research existing data/information…

C11-0-D2: Evaluate implications of possible alternatives or positions related to an STSE issue.

Examples: positive and negative consequences of a decision, strengths and weaknesses of a position…

LEARNING RESOURCES LINKS

Chemistry (Chang 496)

Chemistry (Zumdahl and Zumdahl 524)

Chemistry: The Central Science (Brown, *et al.* 497)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 499)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 515)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 317)

Investigations

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 25—The Effect of Temperature on Soda Water)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 298—The Effect of Temperature on Soda Water)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 318—Solubility of a Gas)

Thermal Pollution

Chemistry (Chang 960)

Chemistry (Zumdahl and Zumdahl 523)

Chemistry: The Central Science (Brown, *et al.* 497)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 499)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 251)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 298)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 764)

SPECIFIC LEARNING OUTCOME

C11-4-10: Explain how a change in pressure affects the solubility of gases.

(0.5 hour)

SLO: C11-4-10

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students will be familiar with the experience of opening a container of a carbonated beverage and having it "whoosh" out the top once the pressure has been released, but they will not likely be able to explain it.

TEACHER NOTES

Teachers can introduce the topic of how a change in pressure affects the solubility of gases by cracking open a can of pop and asking questions for class discussion.

Questions for Class Discussion

Before opening a container of carbonated beverage, ask students to respond to questions such as these:

1. Is this a solution? (*Yes*)
2. What is (are) the solute(s)? (*Carbon dioxide, sugar, citric acid, etc.*)
3. What is the solvent? (*Water*)
4. What type of solution is this? (*Gas-solid-liquid solution*)
5. Are the solutes and solvent polar or non-polar? (*Since water is polar, most of the solutes will be polar. However, carbon dioxide is non-polar and is inserted into the water solution under pressure.*)

After opening the container, ask:

6. Why does the drink make a popping or fizzing noise when you open it? (*When the cap is removed, pressure is released, decreasing the solubility of the gas in the liquid, and the gas escapes.*)

In discussing this topic, students should learn that the solubility of solids and liquids is not affected by pressure but the solubility of a gas in a liquid is greatly affected by pressure.

General Learning Outcome Connections

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

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

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

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

In an established gas/liquid solution (e.g., dissolved CO_2 gas in a carbonated drink), there is a dynamic equilibrium between the rate at which gas particles are entering the solution phase and the number of particles leaving the solution phase. If the pressure above the solution is increased, there will be more gas particles striking the surface. As a result, the rate of dissolving will exceed the rate at which particles are leaving the liquid phase and the solubility of the gas in the liquid will increase. After a while, the equilibrium is re-established at a faster rate, but with more gas dissolved in the solution.

Henry's Law

The mathematical relationship between the partial pressure of a gas over a solution and the solubility of the gas at a fixed temperature is called Henry's Law. (It is not necessary that students remember this relationship.)

The formula for this relationship is: $C = kP$

C = the concentration of the dissolved gas

k = a constant characteristic of a particular solution

P = the partial pressure of the gas over the liquid

This law is most accurate for gases that do not dissociate in or react with the liquid (e.g., Henry's Law is accurate for dissolved oxygen gas but not, for instance, HCl, which easily dissociates in solution).

This relationship is very important to scuba divers (divers using a self-contained underwater breathing apparatus) who are affected by water pressure as they dive. As a diver descends, the ambient pressure increases dramatically. At 40 m (132 ft.) in salt water, the ambient pressure will have risen to about 5 atmospheres (equivalent to ~ 505 kPa). This causes air to become dissolved in the diver's body fluids as solubility increases. The danger is that when the diver ascends, the solubility decreases and the dissolved gases come out of solution. This effect is compounded by the fact that the gas bubbles are also increasing in volume as the pressure decreases around the diver (see Boyle's Law, learning outcome C11-2-05).

These gas bubbles can cause undesirable damage to the body tissues if the ascent is too rapid. To be as safe as possible, divers are required to *ascend slower than the smallest bubbles escaping from their regulators*. This translates to about 20 m per minute. The slower the ascent is, the better it is for the diver.

SPECIFIC LEARNING OUTCOME

C11-4-10: Explain how a change in pressure affects the solubility of gases.

(continued)

Almost every scuba certification body has developed dive tables that enable divers to plan a safe dive according to an assumed physiology. According to these tables, if divers have “maxed out” their bottom time by going too deep or by being there for too long, or both, they would be required to make safety stops as they ascend. This would allow the gas bubbles to escape slowly from their body tissues.

For additional information about scuba diving, contact the nearest scuba certifying agency. The following websites, for example, will provide a list of the diving shops in Manitoba:

- Professional Association of Diving Instructors (PADI): <http://www.padi.com>
- Association of Canadian Underwater Councils (ACUC): <http://www.acuc.ca>

SUGGESTIONS FOR ASSESSMENT

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Journal Writing

Students may want to investigate the world of scuba diving or express their interest in exploring the underwater world of diving through journal entries.

Paper-and-Pencil Tasks

Students should be able to explain the relationship between the external gas pressure above the solution and the solubility of the gas. They should also be able to make several applications of this relationship.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

LEARNING RESOURCES LINKS

Chemistry (Chang 497)

Chemistry (Zumdahl and Zumdahl 521)

Chemistry: The Central Science (Brown, *et al.* 496)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 500)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 460)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 252)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 299)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 340)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 517)

SPECIFIC LEARNING OUTCOME

C11-4-11: Perform a lab to demonstrate freezing-point depression and boiling-point elevation.

(1.5 hours)

SLO: C11-4-11

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Other than knowing that salt placed on ice causes it to melt, students may have no prior experience with freezing-point depression and boiling-point elevation. This learning outcome provides an opportunity to introduce another STSE issue. For, example, students could research where all the salt goes after the ice on the roads melts in the spring.

TEACHER NOTES

The lab activities presented in this document are meant to be qualitative. As the lab investigations outlined for this learning outcome will take considerable time, the class could form groups, with each group doing only one of the experiments.

For a class of 24 students, for example, there could be 12 groups of two students doing the following lab activities:

- Groups 1 and 2: Melting point and freezing point of pure water
- Groups 3, 4, 5, and 6: Melting point and freezing point of salt, NaCl, solution
- Groups 7 and 8: Boiling point of pure water
- Groups 9, 10, 11, and 12: Boiling point of ethylene glycol solution

If students' lab skills have not sufficiently developed by this time, an alternative lab format would need to be considered.

General Learning Outcome Connections

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

GLO C2: Demonstrate appropriate scientific inquiry skills when seeking answers to questions.

GLO C3: Demonstrate appropriate problem-solving skills when seeking solutions to technological challenges.

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

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

Skills and Attitudes Outcomes

C11-0-S5: Collect, record, organize, and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

Laboratory Activities

1. **The Effects of Salt and Antifreeze on the Melting Point of Ice**

   Students repeatedly add specified amounts of coarse salt to an ice and water mixture. They take the temperature of the solution regularly to collect data showing the relationship between the amount of salt added and the present temperature of the salt-ice-water mixture. For a complete lab procedure, see Appendix 4.7: The Effects of Salt and Antifreeze on the Melting Point of Ice.

   If students have not experienced determining the melting point and/or freezing point of water under ambient conditions, this should be done first as a benchmark. The procedure for such an activity is found in many readily available chemistry resources.

2. **The Effect of Antifreeze on the Boiling Point of Water**

   As the boiling point elevation for water is relatively small (0.52°C for a 1 molal solution), students should first measure the actual boiling point (BP) of water in their lab to establish a reference value. The BP for water will most likely be 100 ± 2°C. After students have determined the normal BP for water, they would complete a similar lab using repeated aliquots of ethylene glycol to determine the effect on the boiling point of adding solute. For a complete lab procedure, see Appendix 4.8: The Effect of Antifreeze on the Boiling Point of Water.

3. **Heat Transfer**

   A novel lab activity that students can do easily in one lab period with a minimal amount of equipment is the manufacture of ice cream. The results also taste quite good. For a write-up of this qualitative, enjoyable lab activity, see Appendix 4.9: Heat Transfer: I Scream, You Scream, We All Scream for Ice Cream.

   Extension: One of the student groups could determine the maximum temperature possible with the repeated addition of salt to the ice-water mixture. This lab requires a large amount of salt due to its modest solubility.

4. **Probeware**

   If probeware and computers are available, students can do a lab procedure in which they accurately measure the effect on the freezing point of a pure solvent by adding a solute. See Appendix 4.10: The Effect of Salt on the Melting Point of Ice.

SPECIFIC LEARNING OUTCOME

C11-4-11: Perform a lab to demonstrate freezing-point depression and boiling-point elevation.

(continued)

SUGGESTIONS FOR ASSESSMENT

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Laboratory Reports

The lab activities outlined for this leaning outcome could be assessed as formal lab reports using the Laboratory Report Outline or the Laboratory Report Format (see *SYSTH* 11.38, 14.12) or by using questions and answers from the data collected from the activities.

Journal Writing

1. Students may wish to address an STSE issue by describing the pros and cons of adding salt to the sand used on icy roads in winter.
2. Another journal entry could be devoted to the manufacture of the best ice cream sample.

Paper-and-Pencil Tasks

A series of lab questions and discussion items can be found in the lab procedures associated with each of the lab activities.

Written Reports

Depending on the time available and the enthusiasm of the class, students could write a brief report on the pros and cons of salting ice-covered roads compared to the economic cost of automobile damage from salt corrosion.

SKILLS AND ATTITUDES OUTCOMES

C11-0-S5: Collect, record, organize, and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

LEARNING RESOURCES LINKS

Chemistry (Zumdahl and Zumdahl 531)

Chemistry: The Central Science (Brown, *et al.* 502)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 465)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 506)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 472)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 520)

Activities

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 472—Making of Ice Cream)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 520—Ethylene Glycol Demonstration)

STSE

Chemistry (Chang 504)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 512—Colligative Properties in Industry and Biology)

SPECIFIC LEARNING OUTCOME

C11-4-12: Explain freezing-point depression and boiling-point elevation at the molecular level.

Examples: antifreeze, road salt…

(0.5 hour)

SLO: C11-4-12

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

The only prior knowledge students may have is noted in relation to learning outcome C11-4-11. However, students now have completed the lab to demonstrate freezing-point depression and boiling-point elevation and will be curious about the explanation. Students may be able to propose explanations if they understand the Kinetic Molecular Theory.

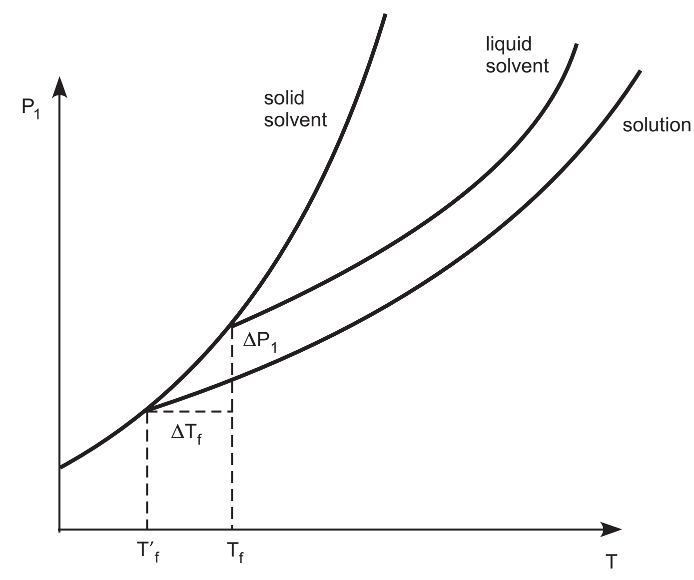
Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

TEACHER NOTES

Most chemistry textbooks provide a triple-point diagram for either the freezing-point depression or the boiling-point elevation (see sample diagram). These diagrams may be difficult for students to understand.

Pressure-Temperature Curve with Triple Point



General Learning Outcome Connections

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

GLO A5: Recognize that science and technology interact with and advance one another.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

Boiling-Point Elevation

If we add solute to a solvent, the vapour pressure of the solution is lowered. A mathematical relationship that relates vapour pressure to the partial pressure of the gas being dissolved is called *Raoult's Law*.

Raoult's Law can be expressed quantitatively as follows: A solvent's vapour pressure in solution is equal to its mole fraction times its vapour pressure as a pure liquid, from which it follows that the freezing-point depression and the boiling-point elevation are directly proportional to the molality of the solute.

Put another way, the addition of solute to a liquid lessens the tendency for the liquid to become a solid or a gas (i.e., the addition reduces the freezing point and the vapour pressure). Teachers will not consider an algorithmic treatment at this level with students.

This complicated relationship can be explained to students by attending to the following considerations:

- At the surface of the solution where evaporation occurs, there are fewer solvent particles due to the presence of solute particles: that is, reduced vapour pressure.
- The solute particles absorb energy and, therefore, reduce the energy available to evaporate the solvent particles: yes, reduced vapour pressure.
- Energy is required to overcome the intermolecular forces between the solute and the solvent particles: again, reduced vapour pressure.

Since the definition of boiling is the temperature at which the vapour pressure equals the pressure above the liquid, it can readily be seen that if the vapour pressure is lowered, it will require additional energy to raise the temperature to where the vapour pressure equals that of the pressure above the solution. Hence, the boiling-point elevation.

Freezing-Point Depression

For a liquid to freeze, it must achieve an ordered state that results in the formation of a crystal. If there are impurities in the liquid (i.e., solute), then the liquid is inherently less ordered. Therefore, a solution is more difficult to freeze than the pure solvent, and a lower temperature is required to freeze the solution.

SPECIFIC LEARNING OUTCOME

C11-4-12: Explain freezing-point depression and boiling-point elevation at the molecular level.

Examples: antifreeze, road salt…

(continued)

Another way to explain this concept is to say that, as a solution is cooled, solvent molecules lose average kinetic energy to enable them to settle into the crystal structure of the pure solvent. As the crystal grows, solute molecules interfere with the growth of the solvent crystals. To compensate, more kinetic energy must be taken from the solution, thus depressing the freezing point.

The examples of antifreeze and salt (identified in the learning outcome) can be used to provide a real-life situation where this relationship is useful.

Point out to students that, logically, any solute that releases more than one particle into the solution when it undergoes solvation would have an even greater effect (e.g., an ionic solid such as $CaCl_2$ releases three ions per one molecule of calcium chloride).

STSE Decision-Making Issue

Learning outcome C11-4-12 provides an opportunity for students to become more aware of their environment by using a local STSE concern linked to the decision-making process.

SUGGESTIONS FOR ASSESSMENT

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Journal Writing

Students may wish to describe what effects the melting-point depression and boiling-point elevation have on their lives.

Paper-and-Pencil Tasks

Students should be able to explain the phenomena of freezing-point depression and boiling-point elevation.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

LEARNING RESOURCES LINKS

Chemistry (Chang 504)

Chemistry (Zumdahl and Zumdahl 531)

Chemistry: The Central Science (Brown, *et al.* 502)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 465)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 506)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 472)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 520)

SPECIFIC LEARNING OUTCOME

C11-4-13: Differentiate among, and give examples of, the use of various representations of concentration.

Include: grams per litre (g/L), % weight-weight (% w/w), % weight-volume (% w/v), % volume/volume (% v/v), parts per million (ppm), parts per billion (ppb), moles per litre (mol/L) (molarity)

(0.5 hour)

SLO: C11-4-13

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students may be familiar with grams per litre (g/L). They may also have seen references to parts per million (ppm) and parts per billion (ppb) in magazines and books. In Grade 7 Science, units of grams solute/100 mL liquid became standard usage for concentration.

TEACHER NOTES

Ensure that students become aware of the various ways in which concentration can be expressed. It is not the intention, however, that students should convert from one unit to another. Percent units are typically used by research facilities that are more interested in being able to make solutions quickly than in having to calculate moles and then concentration.

Representations of Concentrations

g/L = grams of solute in 1 L of solution

$$\% \text{ w/w} = \frac{\text{mass of solute (g)} \times 100}{\text{100 g of solution}}$$

$$\% \text{ w/v} = \frac{\text{mass of solute (g)} \times 100}{\text{100 mL of solution}}$$

$$\% \text{ v/v} = \frac{\text{volume of solute (mL)} \times 100}{\text{100 mL of solution}}$$

ppm = parts per million

Example: 10 ppm sodium ions in water = 10 sodium ions in 1 million particles of water

ppb = parts per billion

Example: 10 ppb iron in water = 10 particles of iron in 1 billion particles of water

General Learning Outcome Connections

GLO C3: Demonstrate appropriate problem-solving skills when seeking solutions to technological challenges.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

Students should know what is meant by molarity. Although *molarity* is not an SI (Système International) unit, it is commonly used as a unit to represent concentration. As we are in a metric learning environment, it is preferred that mol/L be used as much as possible.

$$\textbf{Molarity (M)} = \frac{\text{moles of solute}}{\text{litres of solution}}$$

$$\textbf{Concentration} = \frac{\text{moles of solute}}{\text{litres of solution}}$$ (Some teachers may use **C** for concentration.)

Activity

Have students find magazine or newspaper articles that contain any of the concentration units listed above. Students could display the articles, describe the units, and indicate how they are used in the articles.

Internet Activity

For an Internet activity dealing with solutions, see Appendix 4.11: A WebQuest for Solubility Units.

Sample Concentration Problems

A few sample problems are given below to introduce the next learning outcome (C11-4-14), which requires students to solve concentration problems.

1. Determine the amount of sodium nitrate, $NaNO_3$, required to make 50 mL of a 0.40 mole/L solution.

   Answer:

   Molar mass of $NaNO_3$ is 85.0 g/mol. Using the relationship above, solve for moles of solute:

$$\begin{aligned}\text{Moles} &= \text{concentration} \times \text{L} \\ &= 0.40\ \frac{\text{mole}}{\cancel{\text{L}}} \times 0.050\ \cancel{\text{L}} \\ &= 0.020 \text{ mole of } NaNO_3 \text{ required}\end{aligned}$$

$$\begin{aligned}\text{Mass} &= 0.020\ \cancel{\text{mole}} \times \frac{85.0\ \text{g}}{\cancel{\text{mol}}} \\ &= 1.7\ \text{g required}\end{aligned}$$

SPECIFIC LEARNING OUTCOME

C11-4-13: Differentiate among, and give examples of, the use of various representations of concentration.

Include: grams per litre (g/L), % weight-weight (% w/w), % weight-volume (% w/v), % volume/volume (% v/v), parts per million (ppm), parts per billion (ppb), moles per litre (mol/L) (molarity)

(continued)

2. How much KOH would be required to make 200 mL of solution with a concentration of 2.6 mole/L?

   Answer:

$$\begin{aligned} \text{Moles} &= \text{concentration} \times \text{L} \\ &= 2.6\ \frac{\text{mole}}{\cancel{\text{L}}} \times 0.200\ \cancel{\text{L}} \\ &= 0.52 \text{ mole of KOH required} \\ \text{Mass} &= 0.52\ \cancel{\text{mole}} \times \frac{56.1\ \text{g}}{\cancel{\text{mol}}} \\ &= 29.172 \text{ g or } 29 \text{ g (2 sig. figures) required} \end{aligned}$$

SUGGESTIONS FOR ASSESSMENT

Paper-and-Pencil Tasks

Students should simply be able to recognize the various concentration units and be able to explain what they mean.

Assessment would typically be done with paper-and-pencil exercises and quizzes.

LEARNING RESOURCES LINKS

Chemistry (Chang 139, 491)

Chemistry (Zumdahl and Zumdahl 141)

Chemistry: The Central Science (Brown, *et al.* 498)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 460)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 501)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 462)

Introductory Chemistry: A Foundation (Zumdahl 428)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 255)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 302)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 281)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 123)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 506)

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

NOTES

SPECIFIC LEARNING OUTCOME

C11-4-14: Solve problems involving calculation for concentration, moles, mass, and volume.

(1.0 hour)

SLO: C11-4-14

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students have not received information on solution concentration prior to learning outcome C11-4-13.

TEACHER NOTES

Provide students with sample problems that include the steps necessary to calculate the required variable. Students should also be provided with a good model of the solution to a typical problem involving calculation for concentration, moles, mass, and volume.

Sample Calculation Problems

1. Determine the *concentration* of a solution that contains 2.5 moles of solute dissolved in 5.0 L of solution.

   Answer:

   $$\text{Concentration} = \frac{\text{moles}}{\text{L}} = \frac{2.5 \text{ moles}}{5.0 \text{ L}} = 0.50 \text{ mol/L}$$

2. What *volume* of solution would be required to make a 0.40 mol/L solution dissolving 0.10 moles of solute?

   Answer:

   $$\text{Volume (L)} = \frac{\text{moles}}{\text{concentration } \left(\text{mol/L}^{-1}\right)}$$

   $$\text{Volume} = \frac{0.10 \ \cancel{\text{mol}}}{0.40 \ \cancel{\text{mol}}/\text{L}^{-1}}$$

   The moles units cancel, leaving the answer in L.

   Volume = 0.25 L (2 sig. figures)

General Learning Outcome Connections

GLO C3: Demonstrate appropriate problem-solving skills when seeking solutions to technological challenges.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

Skills and Attitudes Outcomes

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

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3. Calculate the *mass* of ammonium hydroxide, NH_4OH, required to prepare 0.30 L of a 0.25 mol/L solution.

   Answer:

   $$\text{Mass} = \text{concentration} \times \text{litres}$$

   $$= 0.25\ \frac{\cancel{\text{mol}}}{\text{L}} \times 0.30\ \cancel{\text{L}}$$

   $$\text{Mass} = 0.075\ \cancel{\text{mol}} \times \frac{35.0\ \text{g}}{\cancel{\text{mol}}}$$

   $$= 2.6\ \text{g (2 sig. figures)}$$

4. Calculate the *concentration* of a solution if 44.0 g of lithium sulphate, Li_2SO_4, is dissolved in 0.400 L of solution.

   Answer:

   $$\text{Moles} = \frac{44.0\ \cancel{\text{g}}}{109.98\ \cancel{\text{g}}/\text{mol}}$$

   $$= 0.400\ \text{mol}$$

   $$C = \frac{\text{mol}}{\text{L}}$$

   $$= \frac{0.400\ \text{mol}}{0.400\ \text{L}}$$

   $$= 1.00\ \text{mol/L (3 sig. figures)}$$

Specific Learning Outcome

C11-4-14: Solve problems involving calculation for concentration, moles, mass, and volume.

(continued)

5. What *volume* would be required to make a 0.400 moles/L solution containing 51.01 g of sodium nitrate, $NaNO_{3(aq)}$?

   Answer:

$$\text{Moles} = \frac{51.01\ \cancel{\text{g}}}{85.01\ \cancel{\text{g}}/\text{mol}}$$

$$= 0.600\ \text{mol}$$

$$\text{Litres} = \frac{\text{moles}}{\text{concentration}}$$

$$= \frac{0.600\ \cancel{\text{mol}}}{0.400\ \cancel{\text{mol}}/\text{L}}$$

$$= 1.50\ \text{L (3 sig. figures)}$$

Suggestions for Assessment

Paper-and-Pencil Tasks

Students should be able to solve problems involving calculation for concentration, moles, mass, and volume. Assessment would typically be done with paper-and-pencil exercises and tests.

Learning Resources Links

Chemistry (Zumdahl and Zumdahl 139, 141)

Chemistry: The Central Science (Brown, *et al.* 136)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 462)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 502)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 464)

Introductory Chemistry: A Foundation (Zumdahl 430)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 266)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 313)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 283)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 126)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 507)

Skills and Attitudes Outcomes

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

Notes

SPECIFIC LEARNING OUTCOME

C11-4-15: Prepare a solution, given the amount of solute (in grams) and the volume of solution (in millilitres), and determine the concentration in moles/litre.

(1.0 hour)

SLO: C11-4-15

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students have had no experience at accurately preparing solutions. Learning outcome C11-4-13 introduced concentration units and learning outcome C11-4-14 required students to solve concentration problems.

TEACHER NOTES

For this learning outcome, prepare solutions that could be used for learning outcome C11-4-17, where students prepare a dilution from a solution of known concentration.

Examples:

Prepare 0.10 mol/L solutions of

- copper(II) sulphate, $CuSO_4$
- cobalt(II) chloride, $CoCl_2$
- sodium chloride, NaCl

Laboratory Procedure for Preparing Solutions

The focus of this lab activity should be on lab safety, accuracy, and precision. Wherever possible, students should use volumetric flasks to make the solutions.

The procedure could be as follows:

Measure out a given amount of solute onto a pre-weighed piece of paper. Then, *quantitatively* transfer the solid to the appropriate volumetric flask using a glass funnel and a squirt bottle filled with distilled or deionized water. The water is used to ensure that all the solute has been transferred to the flask. Wash the sides of the flask with the water. Fill the flask to approximately two-thirds full. Then, dissolve the solute completely by carefully swirling the flask. Carefully increase the level of the solution with water until the correct level is reached. (**Note:** Students should at first use an eyedropper to add the final amount of water. Once students are more proficient, they could use the squirt bottle to add the final volume.) Once the

General Learning Outcome Connections

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

GLO C2: Demonstrate appropriate scientific inquiry skills when seeking answers to questions.

GLO C3: Demonstrate appropriate problem-solving skills when seeking solutions to technological challenges.

SKILLS AND ATTITUDES OUTCOMES

C11-0-S4: Select and use scientific equipment appropriately and safely.
Examples: volumetric glassware, balance, thermometer…

C11-0-S6: Estimate and measure accurately using Système International (SI) and other standard units.
Include: SI conversions, significant figures

---

correct amount of water has been added, insert a stopper into the flask. Shake the contents of the flask to ensure the homogeneity of the resulting solution.

Performance Task: Laboratory Skills

Example:

Prepare 100.0 mL of a solution using 5.85 g of sodium chloride, NaCl. What would be the concentration of the prepared solution?

Calculation:

$$\text{Moles of NaCl} = \frac{5.85\ \cancel{g}}{58.5\ \cancel{g} \cdot \text{mol}^{-1}}$$

$$\text{Moles} = 0.100\ \text{mol}$$

$$\text{Concentration} = \frac{\text{moles}}{\text{L}}$$

$$= \frac{0.100\ \text{mol}}{0.1000\ \text{L}}$$

$$= 1.00\ \text{mol/L (3 sig. figures)}$$

Procedure:

1. Place a small piece of smooth paper on the balance and carefully weigh it. Record the mass of the paper.
2. Next, tap and rotate the container of NaCl to get 5.85 g. Remember, if too much is added, turn off the balance or arrest the pan and carefully remove more than you think you need to. To avoid contamination, DO NOT put the removed NaCl back into the original container. Turn on the balance and continue to add NaCl until the correct mass is obtained.
3. Using a 100 mL volumetric flask, carefully place a clean glass filter funnel into the neck of the flask, making sure that the apparatus does not fall over. Carefully pour the NaCl from the weighing paper into the funnel. Gently wash the solid through the funnel using a squeeze bottle containing either distilled or deionized water. Remove the funnel and wash its sides with the same water.
4. Remove the funnel and fill the flask to approximately two-thirds of its volume. Stopper or cover the flask with *parafilm* or by some other means.

SPECIFIC LEARNING OUTCOME

C11-4-15: Prepare a solution, given the amount of solute (in grams) and the volume of solution (in millilitres), and determine the concentration in moles/litre.

(continued)

5. Carefully swirl the flask until all the solid has dissolved. It is crucial to ensure that all the solid is completely transferred. Add distilled water to the flask until the correct volume has been reached.
6. Shake the contents of the flask to ensure the homogeneity of the resulting solution.

Laboratory Activity

Have students do a lab investigation to determine the concentration of a given sample of solution. Part of the investigation involves designing the procedures required to solve the problem.

SUGGESTIONS FOR ASSESSMENT

Rubrics/Checklists

For the performance lab, create a short skill-based rubric to assess a predetermined set of skills. See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Laboratory Reports

The lab activities outlined for this leaning outcome could be assessed as formal lab reports using the Laboratory Report Outline or the Laboratory Report Format (see *SYSTH* 11.38, 14.12) or by using questions and answers from the data collected from the activities.

Journal Writing

Have students comment on the source of errors for the lab activities. Sources of errors could include

- massing errors
- mass loss during transfers
- incorrect volume added

Paper-and-Pencil Tasks

Students could be asked to describe the correct order of the procedure to prepare a solution similar to the one outlined in the Suggestions for Instruction for this learning outcome. They could be also asked to discuss the relative importance of the various errors.

SKILLS AND ATTITUDES OUTCOMES

C11-0-S4: Select and use scientific equipment appropriately and safely.
Examples: volumetric glassware, balance, thermometer…

C11-0-S6: Estimate and measure accurately using Système International (SI) and other standard units.
Include: SI conversions, significant figures

LEARNING RESOURCES LINKS

Chemistry (Zumdahl and Zumdahl 144)

Chemistry: The Central Science (Brown, *et al.* 135)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 461)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 116)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 466)

Introductory Chemistry: A Foundation (Zumdahl 433)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 271)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 319)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 300)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 508)

Laboratory Activity

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 301)

SPECIFIC LEARNING OUTCOME

C11-4-16: Solve problems involving the dilution of solutions.

Include: dilution of stock solutions, mixing common solutions with different volumes and concentrations

(1.5 hours)

SLO: C11-4-16

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Other than being able to solve concentration problems (learning outcome C11-4-14), students will have no prior knowledge of solving dilution problems.

TEACHER NOTES

In solving problems involving the dilution of solutions, students should learn to recognize that when a dilution occurs, the number of moles remains constant. Many teachers and texts use the following general formula or modification of the formula for solving these problems:

$$C_1 \times V_1 = C_2 \times V_2$$

When students are given this relationship without a careful explanation, they may become confused. Teachers may wish to use this formula only after students can solve problems without it. Many students will come up with this relationship themselves.

Sample Dilution Problems

1. Calculate the final concentration when 75.0 mL of water is added to 25.0 mL of an 8.00 mol/L of HCl.

   Answer:

$$\text{Moles (of original solution)} = \frac{\text{moles}}{\text{L}} \times \text{L}$$

$$\text{Moles} = 8.00\ \frac{\text{moles}}{\cancel{\text{L}}} \times 0.0250\ \cancel{\text{L}}$$

$$\text{Moles} = 0.200 \text{ moles}$$

General Learning Outcome Connections

GLO C3: Demonstrate appropriate problem-solving skills when seeking solutions to technological challenges.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

Since only water is being added, the moles of solute are constant and we can write:

$$\text{Concentration (of final solution)} = \frac{\text{moles}}{\text{L (final volume)}}$$

$$C = \frac{0.200 \text{ moles}}{(0.025 + 0.075) \text{ L}}$$

$$C = 2.00 \text{ moles/L}$$

2. What volume of water must be added to 150.0 mL of a 5.00 mol/L solution of NaOH (sodium hydroxide) to make a 2.00 mol/L solution?

   This type of problem is very common in most research laboratories, hospital laboratories, and so on. Technicians will often prepare stock solutions to be diluted when needed.

   Answer:

   Initial solution moles = C x V

$$= \frac{5.00 \text{ mol}}{\cancel{\text{L}}} \times 0.150 \cancel{\text{L}}$$

$$= 0.750 \text{ mol}$$

   Since the moles will be constant again, we can use initial moles to find the final volume of water.

$$\text{Final volume} = \frac{\text{final moles (same as initial)}}{\text{final concentration}}$$

$$= \frac{0.750 \cancel{\text{mol}}}{2.00 \cancel{\text{mol}} \cdot \text{L}^{-1}}$$

$$= 0.375 \text{ L}$$

   The volume added would be 375 – 150 mL = 225 mL

   Another option is doing a calculation with stock solutions.

SPECIFIC LEARNING OUTCOME

C11-4-16: Solve problems involving the dilution of solutions.
Include: dilution of stock solutions, mixing common solutions with different volumes and concentrations

(continued)

3. Calculate the volume of stock 18.0 mol/L H_2SO_4 (sulphuric acid) that would be required to make 300.0 mL of 3.00 mol/L solution.

   Answer:

   $$\text{Moles (in final solution)} = \frac{\text{moles}}{\text{L}}\text{(final)} \times \text{L (final)}$$

   $$\text{Moles} = 3.00\ \frac{\text{moles}}{\cancel{\text{L}}} \times 0.300\ \cancel{\text{L}}$$

   $$\text{Moles} = 0.900\ \text{mol}$$

   Since only water is being added, the moles of solute are constant and we can write:

   $$\text{Volume (of stock solution)} = \frac{\text{moles (initial)}}{\text{concentration (initial)}}$$

   $$\text{Volume} = \frac{0.900\ \cancel{\text{moles}}}{18.0\ \cancel{\text{moles}}/\text{L}}$$

   $$\text{Volume} = 0.0500\ \text{L}$$

   The dilution would be made by adding 50.0 mL of 18.0 mol/L stock solution of H_2SO_4 to a 300.0 mL volumetric flask and adding the appropriate volume of distilled water to the full mark of the flask.

4. If 45.0 mL of stock HCl was required to make 150.0 mL of a 3.48 mol/L solution, calculate the concentration of the original stock solution.

   Answer:

   We can calculate the moles that are constant between the final solution and the original stock solution.

   Final moles = final concentration x final volume

   $$= \frac{3.48\ \text{mol}}{\cancel{\text{L}}} \times 0.1500\ \cancel{\text{L}}$$

   $$= 0.522\ \text{mol}$$

   Since this number of moles was taken from the original stock HCl solution, we can now calculate the original concentration.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

$$\text{Final concentration} = \frac{\text{initial moles (same as final)}}{\text{initial volume}}$$

$$= \frac{0.522 \text{ mol}}{0.450 \text{ L}}$$

$$= 11.6 \text{ mol/L}$$

The initial concentration of the stock HCl acid = 11.6 mol/L.

Note: The second type of dilution problem involves solutions having the same solute and solvent, and are mixed together.

5. What would be the final volume and concentration if 50.0 mL of 0.250 mol/L NaOH is added to 75.0 mL of 0.450 mol/L solution of NaOH?

Answer:

Students should first be asked what solution characteristics are the same and what characteristics are different before and after the solutions are mixed.

- Volumes are different.
- Concentrations are different.
- Solute is the same.
- Solvent is the same.

There should be no reaction, so moles of each solution should be additive.

We should, therefore, calculate the moles of each solution, add them, and divide by the new total volume according to C = moles/litres.

Moles of solution 1 = concentration #1 x volume #1

$$= \frac{0.250 \text{ mol}}{\cancel{\text{L}}} \times 0.050 \ \cancel{\text{L}}$$

$$= 0.0125 \text{ mol}$$

Moles of solution 2 = concentration #2 x volume #2

$$= \frac{0.450 \text{ mol}}{\cancel{\text{L}}} \times 0.0750 \ \cancel{\text{L}}$$

$$= 0.03375 \text{ mol}$$

SPECIFIC LEARNING OUTCOME

C11-4-16: Solve problems involving the dilution of solutions.

Include: dilution of stock solutions, mixing common solutions with different volumes and concentrations

(continued)

$$\text{Final concentration} = \frac{\text{moles 1} + \text{moles 2}}{\text{volume 1} + \text{volume 2}}$$

$$= \frac{0.0125 \text{ mol} + 0.03375 \text{ mol}}{0.050 \text{ L} + 0.0750 \text{ L}}$$

$$= 0.370 \text{ mol/L}$$

This answer seems reasonable, as the initial volumes of the two solutions are similar and the final concentration is between the concentrations of the two original solutions.

SUGGESTIONS FOR ASSESSMENT

Paper-and-Pencil Tasks

Solving problems involving the dilution of solutions would usually be assessed with exercises and quizzes.

LEARNING RESOURCES LINKS

Chemistry (Chang 141)

Chemistry (Zumdahl and Zumdahl 145)

Chemistry: The Central Science (Brown, *et al.* 137)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 467)

Introductory Chemistry: A Foundation (Zumdahl 434)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 272)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 320)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 302)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 134)

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…

NOTES

SPECIFIC LEARNING OUTCOME

C11-4-17: Perform a dilution from a solution of known concentration.

(1.0 hour)

SLO: C11-4-17

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students would most likely not have done a dilution procedure, although they will have prepared solutions and used volumetric glassware (learning outcome C11-4-15).

TEACHER NOTES

Have students use one of the solutions prepared in the development of learning outcome C11-4-15 to perform a dilution. Ask students to design the procedure for this task. Check the procedure and have students make the necessary revisions.

Students should use volumetric flasks and pipettes whenever possible. The alternative would be to use graduated cylinders and pipettes.

Procedure for Performing a Serial Dilution

There are many ways to conduct a *serial dilution*. Essentially, repeated aliquots are taken from each successive dilution.

Performance Task: Laboratory Skills

The suggested procedure for the dilution of 1.00 mol/L solution to a 0.001 mol/L solution is as follows:

1. Carefully pipette 10.0 mL of stock solution and dispense it into a clean volumetric flask.
2. Add water until the flask is approximately two-thirds full, and mix the solution.
3. Carefully add water until it exactly reaches the 100.0 mL mark of the volumetric flask.
4. The flask can now be stoppered and the solution mixed thoroughly.

General Learning Outcome Connections

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

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-R1: Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

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The concentration of this solution will be:

$$\frac{10\ \cancel{\text{mL}}}{100\ \cancel{\text{mL}}} \times 1.00\ \text{mol/L} = 0.100\ \text{mol/L}$$

This becomes the new "stock" solution, and the process is repeated:

1. Carefully pipette 10.0 mL of stock solution and then dispense into a clean volumetric flask.
2. Add water to approximately two-thirds of the flask volume and then mix the solution.
3. Carefully add water until it exactly reaches the 100.0 mL mark of the volumetric flask.
4. The flask can now be stoppered and the solution mixed thoroughly.

The concentration of this solution will be:

$$\frac{10\ \cancel{\text{mL}}}{100\ \cancel{\text{mL}}} \times 0.100\ \text{mol/L} = 0.0100\ \text{mol/L}$$

This becomes the new "stock" solution, and the process is repeated.

The concentration of this solution will be:

$$\frac{10\ \cancel{\text{mL}}}{100\ \cancel{\text{mL}}} \times 0.0100\ \text{mol/L} = 0.00100\ \text{mol/L}$$

Serial dilutions are used extensively in microbiology where lab technicians dilute stock solution of media for the specialized growth of bacteria.

SUGGESTIONS FOR ASSESSMENT

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

For the performance lab, teachers will be carefully watching students for correct procedure. A performance rubric from Appendix 10 can be used to assess student success in this lab activity.

SPECIFIC LEARNING OUTCOME

C11-4-17: Perform a dilution from a solution of known concentration.

(continued)

Laboratory Reports

The lab activities outlined for this leaning outcome could be assessed as formal lab reports using the Laboratory Report Outline or the Laboratory Report Format (see *SYSTH* 11.38, 14.12) or by using questions and answers from the data collected from the activities.

LEARNING RESOURCES LINKS

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 467)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 305)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 134)

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-R1: Synthesize information obtained from a variety of sources.

Include: print and electronic sources, specialists, other resource people

NOTES

SPECIFIC LEARNING OUTCOME

C11-4-18: Describe examples of situations where solutions of known concentration are important.

Examples: pharmaceutical preparations, administration of drugs, aquaria, swimming-pool disinfectants, gas mixes for scuba, radiator antifreeze…

(1.5 hours)

SLO: C11-4-18

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students will likely have prior experience with some of the examples identified in learning outcome C11-4-18. It is hoped that students will be able to provide some of their own examples.

Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

TEACHER NOTES

Many examples of solutions can be found around most households. The concentration information for the solutions is given in a variety of ways.

Products Found at Home

It would be beneficial to students if they were able to collect their own samples of solutions among the domestic products found at home. Nevertheless, some examples are provided below as guidance. Students could augment and refine the information provided here by obtaining additional information from the labelling on products. The examples listed here identify the manner in which concentrations vary widely in their use of units or volumetric data.

General Learning Outcome Connections

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

GLO A5: Recognize that science and technology interact with and advance one another.

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

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

SKILLS AND ATTITUDES OUTCOMES

C11-0-R1: Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

C11-0-R2: Evaluate information obtained to determine its usefulness for information needs.
Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…

C11-0-R3: Quote from or refer to sources as required and reference information sources according to an accepted practice.

C11-0-R5: Communicate information in a variety of forms appropriate to the audience, purpose, and context.

Examples:

- Vicks® VapoRub®: camphor 4.73% w/w
- Curél® moisturizer: glycerine 12% w/w
- rubbing alcohol: 40% v/v
- Aquafina® bottled water: fluoride ion, 0.3 ppm
- Roundup®: 7g/L glyphosate
- liquid ant killer: 5.4% w/v borax

Pharmacy Preparations

Most ointments exceeding certain concentrations are dispensed by a qualified pharmacist.

Example:

- medicated dermatitis cream: 0.5% w/w betamethasone (an over-the-counter equivalent has a 0.1% w/w concentration)

Dental Surgery

Dentists will often use epinephrine in anaesthetic as a vasodilator to ensure that the anaesthetic is not flushed as rapidly from the tissues of the oral cavity.

Example:

- xylocaine hydrochloride 2% with 1:50,000 epinepherine (20 ppm)

Automobile Antifreeze

Example:

- For one brand of commercial antifreeze/coolant, the container lists the following concentrations: For protection from freezing down to –52°C, dilute to a 60% v/v solution; and for further protection to –64°C, dilute to a 70% v/v solution.

SPECIFIC LEARNING OUTCOME

C11-4-18: Describe examples of situations where solutions of known concentration are important.

Examples: pharmaceutical preparations, administration of drugs, aquaria, swimming-pool disinfectants, gas mixes for scuba, radiator antifreeze…

(continued)

Fish Aquaria

Nitrogen as ammonia in fish tanks must be carefully balanced to ensure fish remain healthy. The following table provides recommended concentrations in mg/L (ppm) of ammonia at various pH values.

pH	20°C	25°C
6.5	15.4	11.1
7.0	5.0	3.6
7.5	1.6	1.2
8.0	0.5	0.4
8.5	0.2	0.1

Reference: The Fishtank Crew: <http://pcpages.com/fish/nitrogen1.html>

Swimming-Pool Solutions

The chlorine in swimming pools is carefully controlled as a disinfectant against bacteria and other micro-organisms.

Example:

- free chlorine, Cl_2, is usually kept between 1.0 and 2.5 ppm.

The use of chlorine as a disinfectant has come under scrutiny lately as a potential human biohazard. For background information, see the following website:

AZCO Industries Limited: <http://www.azco.bc.ca/info/chlorine.htm>

Recreational Scuba

When a number of gases are placed together in the same container, the resulting system could be called either a gas mixture or a solution of miscible gases blended together. Scuba diving has become both safer and more complex with the use of Nitrox mixtures in which the percentage of oxygen in air is increased and the percentage of nitrogen is decreased. By reducing the amount of nitrogen, divers are able to make longer dives to the same depth. Specialized instruction and certification is required for divers to use Nitrox mixtures. Excess nitrogen dissolved in the blood supply is the causal factor in *decompression sickness*, also known as *the bends*. The physiological effects of this situation often have outward manifestations such as severe muscle cramping and delirium, hence the reference to *bending*.

SKILLS AND ATTITUDES OUTCOMES

C11-0-R1: Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

C11-0-R2: Evaluate information obtained to determine its usefulness for information needs.
Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…

C11-0-R3: Quote from or refer to sources as required and reference information sources according to an accepted practice.

C11-0-R5: Communicate information in a variety of forms appropriate to the audience, purpose, and context.

The following table, illustrating examples of gas mixtures, provides the maximum time permissible, for a particular depth, before decompression is required on ascent. EAN is Enriched Air Nitrox. EAN 32 is 32% O_2 as opposed to the normal 21% O_2 in air.

A Comparison of Dive Times for Various Gas Mixtures
(Dive Times in Minutes)

Depth (ft.)	Air	EAN 32	EAN 36
50	80	200	200
60	55	100	100
70	45	60	60
80	35	50	60
90	25	40	50
100	22	30	40
110	15	25	30
120	12	25	n/a

Reference: Oakley, Burks II. *Nitrox Scuba Diving*. University of Illinois at Springfield. 30 April 2000. <http://www.online.uillinois.edu/oakley/nitrox.html>.

SUGGESTIONS FOR ASSESSMENT

This learning outcome illustrates another valid reason for students to study chemistry. Students should be able to provide examples of solutions found in their daily lives.

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

SPECIFIC LEARNING OUTCOME

C11-4-18: Describe examples of situations where solutions of known concentration are important.

Examples: pharmaceutical preparations, administration of drugs, aquaria, swimming-pool disinfectants, gas mixes for scuba, radiator antifreeze…

(continued)

Research Reports

If there is time for students to collect further examples of situations where different solutions are found, the information collected could be presented as

- written reports
- oral presentations
- bulletin board displays

Visual Displays

Depending on the information collected, students could present the material using

- posters
- pamphlets
- bulletin boards
- models

Each of these presentation styles could be assessed using an appropriate rubric created with students prior to the assignment. Samples of presentation rubrics are provided in Appendix 10 of this document.

LEARNING RESOURCES LINKS

Chemistry: The Central Science (Brown, *et al.* 137—the aura of gold)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 468—reverse osmosis)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 503—pheromones, 512—uses of colligative properties)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 463—aquarium salt concentration, 468—fluoridation of water)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 302—MSDS of household products, 306—mass/mass alloys)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 281—consumer products)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 123)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 504—aquaria concentrations)

SKILLS AND ATTITUDES OUTCOMES

C11-0-R1: Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

C11-0-R2: Evaluate information obtained to determine its usefulness for information needs.
Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…

C11-0-R3: Quote from or refer to sources as required and reference information sources according to an accepted practice.

C11-0-R5: Communicate information in a variety of forms appropriate to the audience, purpose, and context.

NOTES

SPECIFIC LEARNING OUTCOME

C11-4-19: Describe the process of treating a water supply, identifying the allowable concentrations of metallic and organic species in water suitable for consumption.

(1.0 hour)

SLO: C11-4-19

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Many rural students may be familiar with the processes associated with water treatment due to their proximity to a community water-treatment plant.

Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

TEACHER NOTES

The intent of learning outcome C11-4-19 is for students to gain an appreciation of the methods used to treat their own local water supply. Discussion will undoubtedly include the local source for water, water treatment, water purity, and the shortage of clean potable water for much of the world's population.

General Learning Outcome Connections

GLO A5: Recognize that science and technology interact with and advance one another.

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

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

GLO C2: Demonstrate appropriate scientific inquiry skills when seeking answers to questions.

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

SKILLS AND ATTITUDES OUTCOMES

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.

Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

C11-0-D1: Identify and explore a current STSE issue.

Examples: clarify what the issue is, identify different viewpoints and/or stakeholders, research existing data/information…

C11-0-D2: Evaluate implications of possible alternatives or positions related to an STSE issue.

Examples: positive and negative consequences of a decision, strengths and weaknesses of a position…

C11-0-D3: Recognize that decisions reflect values and consider their own values and those of others when making a decision.

Examples: being in balance with nature, generating wealth, respecting personal freedom…

C11-0-A1: Demonstrate confidence in their ability to carry out investigations in chemistry and to address STSE-related issues.

World Water Shortages

The following information regarding the world reservoirs of water may provide a starting point for a discussion about world water shortages.

The Earth's Water Supply

Reservoir	Volume (km^3)	Percent of Total Time
Atmospheric moisture expressed as water	15×10^3	0.001
Rivers and lakes	510×10^3	0.036
Groundwater	5100×10^3	0.365
Glacial and other land ice	$22,950 \times 10^3$	1.641
Oceanic water and sea ice	$1,370,323 \times 10^3$	97.957
Total	$1,398,898 \times 10^3$	100

The Earth's Water Supply: Reproduced from page 33 of *Fundamentals of Oceanography* by Alison B. Duxbury and Alyn C. Duxbury. Copyright © 1996 The McGraw-Hill Companies, Inc.

Water-Treatment Processes

Water-treatment plants use a variety of treatment processes, including

- settling tanks
- filtration
- addition of chemicals
- aeration
- chlorination
- fluorination

SPECIFIC LEARNING OUTCOME

C11-4-19: Describe the process of treating a water supply, identifying the allowable concentrations of metallic and organic species in water suitable for consumption.

(continued)

If students use well water, they should also explore the process by which their own water is treated. Possible treatments include

- distillation
- use of water softeners
- reverse osmosis

For an explanation and a series of questions related to domestic reverse osmosis techniques, see selected learning resources, consult a local water supply firm, or see the information provided on the Pure Water Products website: <http://www.pwgazette.com/rofaq.htm>.

Ideally, the class will be able to visit a local treatment plant where students can see water treatment first-hand. Prior to the tour, provide students with a working knowledge of water-treatment processes so they can ask informed questions while on the tour. Class reports of the tour could be made either orally or in writing.

The Manitoba Water Stewardship Branch website (at <http://www.gov.mb.ca/waterstewardship/odw/index.html>) provides a map of Manitoba communities with the location of their water supply and treatment facilities. By accessing this website, students can locate the water-treatment plant that is nearest to their community.

Research Activity

Have students research their own water supply and identify where and how it is treated. The Manitoba Water Stewardship Branch website provides local information. The Internet and print texts will provide a wealth of general information about water-treatment processes. Text references can be found in the Learning Resources Links cited for this learning outcome. Both the online and print resources provide diagrams of treatment plants that students could recreate for display purposes.

STSE Decision-Making Issue

This learning outcome provides another opportunity for students to use the research they have collected to make STSE decisions regarding their own water supply.

SKILLS AND ATTITUDES OUTCOMES

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

C11-0-D1: Identify and explore a current STSE issue.
Examples: clarify what the issue is, identify different viewpoints and/or stakeholders, research existing data/information…

C11-0-D2: Evaluate implications of possible alternatives or positions related to an STSE issue.
Examples: positive and negative consequences of a decision, strengths and weaknesses of a position…

C11-0-D3: Recognize that decisions reflect values and consider their own values and those of others when making a decision.
Examples: being in balance with nature, generating wealth, respecting personal freedom…

C11-0-A1: Demonstrate confidence in their ability to carry out investigations in chemistry and to address STSE-related issues.

Activities

Students could participate in the following activities:

1. **Role-Play:** Students hold a community town-hall meeting about water safety/treatment. They could play the roles of police officers, game wardens, local business owners, reporters from local newspapers, delegates from recreational clubs around town, and so on.
2. **Debate:** Students debate the cost versus effectiveness of water treatment.
3. **Court Case:** The class stages a court case over animals being poisoned by a local big business contaminating the local water supply.

Similar activities could be done for water softening as for water treatment.

STSE Issues: Exploring Bottled Water Issues

Worldwide, the bottled water industry was estimated to generate sales of 50 to 100 billion dollars per year as of 2005, and this constitutes about 150 billion litres consumed. That is the equivalent of a freshwater lake that contains 150,000,000 m^3 of water. According to the Beverage Marketing Corporation in the United States, North Americans drink an average of 400 mL of bottled water per day/person.

Provide students with the opportunity to investigate the following:

1. Sample a drinking water supply from home, or the school, and have it tested for amounts of dissolved solids and available chlorine (if treated).
2. Compare these results with those from a sample of bottled water that has had its labelling removed. Compare and contrast the results of the chemistry of these samples.
3. In past years, Winnipeg's water supply from Shoal Lake in the Whiteshell of Manitoba has consistently ranked among the world's top 10 in terms of quality and purity. Investigate this claim more fully, and then ask questions such as, "Why do Manitobans drink so much bottled water?"

SPECIFIC LEARNING OUTCOME

C11-4-19: Describe the process of treating a water supply, identifying the allowable concentrations of metallic and organic species in water suitable for consumption.

(continued)

SUGGESTIONS FOR ASSESSMENT

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Research Reports

Have students work individually or in small groups to research and report on the treatment of their local water supply. The information collected could be presented as

- written reports
- oral presentations
- bulletin board displays
- multimedia presentations

Visual Displays

Students could present the material they have collected using

- posters
- pamphlets
- bulletin boards
- models

Each of these presentation styles could be assessed using an appropriate rubric created with students prior to the assignment. Samples of presentation rubrics are provided in Appendix 10 of this document.

Journal Writing

Provide students with an opportunity to make personal comments about the state of our water supply, its abuse, water treatment concerns, and so on.

Topic-Review Activity

For an activity to review Topic 4, see Appendix 4.12: Solutions: Scavenger Hunt. Teachers could create their own set of questions to relate more specifically to their emphases, presentations, findings, and so on.

SKILLS AND ATTITUDES OUTCOMES

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

C11-0-D1: Identify and explore a current STSE issue.
Examples: clarify what the issue is, identify different viewpoints and/or stakeholders, research existing data/information…

C11-0-D2: Evaluate implications of possible alternatives or positions related to an STSE issue.
Examples: positive and negative consequences of a decision, strengths and weaknesses of a position…

C11-0-D3: Recognize that decisions reflect values and consider their own values and those of others when making a decision.
Examples: being in balance with nature, generating wealth, respecting personal freedom…

C11-0-A1: Demonstrate confidence in their ability to carry out investigations in chemistry and to address STSE-related issues.

LEARNING RESOURCES LINKS

Chemistry: The Central Science (Brown, *et al.* 722)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 520)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 185, 864)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 804)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 357)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 291)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 266)