IMPLEMENTATION

The Senior Years Student and the Science Learning Environment

Each year, teachers are called upon to make a myriad of decisions regarding course content, learning materials and resources, and instructional and assessment methods. Successful learning is more likely to occur if these decisions are informed by teachers' understanding of their students and the ways they learn.

Teachers seeking to learn about their students need to be knowledgeable in various areas, including the following:

- **How people learn:** In recent decades, cognitive psychology, brain-imaging technology, and multiple intelligences theory have transformed our understanding of learning. Ongoing professional development is important to teachers as they seek to update their knowledge of the processes of learning.
- **The ways in which student populations are changing:** The students whom teachers encounter today are different in many respects from students a generation ago. Students are more likely to be living with a single parent or stepfamily. More have part-time jobs. Students are more sophisticated in their knowledge and use of information technology, and much of their understanding of the world comes from television. Classrooms are more likely to be ethnically diverse.
- **The developmental characteristics of Grade 12 students:** The characteristics of adolescent learners have many implications for teachers.
- **The unique qualities of each student:** Family relationships, academic and life experiences, personality, interests, learning approaches, socio-economic status, and rate of development all influence a student's ability to learn. Teachers can gain an understanding of the unique qualities of each student only through daily interaction, observation, and assessment.

Characteristics of Grade 12 Learners

For many students, Grade 12 is a stable and productive year. Many Grade 12 students have developed a degree of security within their peer group and a sense of belonging in school. They show increasing maturity in dealing with the freedoms and responsibilities of late adolescence: romantic relationships, part-time jobs, a driver's license. In Grade 12, most students have a great deal of energy and a growing capacity for abstract and critical thinking. Many are prepared to express themselves with confidence and to take creative and intellectual risks. The stresses and preoccupations of preparing for graduation, post-secondary education, or full-time jobs are still a year away. For many students, Grade 12 may be the most profitable academic year of the Senior Years.

Although many Grade 12 students handle their new responsibilities and the demands on their time with ease, others experience difficulty. External interests may seem more important than school. Because of their increased autonomy, students who previously had problems managing their behaviour at school may now express their difficulties through poor attendance, alcohol and drug use, or other behaviours that place them at risk.

Students struggling to control their lives and circumstances may make choices that seem to teachers to be contrary to their best interests. Communication with the home and awareness of what their students are experiencing outside school continue to be important for Grade 12 teachers. Although the developmental variance evident in Grade 6 through Senior 2 has narrowed, students in Grade 12 can still change a great deal in the course of one year or even one semester. Grade 12 teachers need to be sensitive to the dynamic classroom atmosphere and recognize when shifts in interests, capabilities, and needs are occurring, so they can adjust learning experiences for their students.

The chart on the following pages identifies some common characteristics of late adolescence observed in educational studies (Glatthorn, 1993; Maxwell and Meiser, 1997; Probst, 1988) and by Manitoba teachers, and discusses the implications of these characteristics for teachers.

Grade 12 Learners: Implications for Teachers*	
Characteristics of Grade 12 Learners	**Significance for Grade 12 Teachers**
Cognitive Characteristics	
• Most Grade 12 learners are capable of abstract thought and are in the process of revising their former concrete thinking into fuller understanding of principles.	• Teach to the big picture. Help students forge links between what they already know and what they are learning. Be cognizant of individual differences and build bridges for students who think concretely.
• Students are less absolute in their reasoning, more able to consider diverse points of view. They recognize that knowledge may be relative to context.	• Focus on developing problem-solving and critical thinking skills, particularly those related to STSE and decision making.
• Many basic learning processes have become automatic by Grade 12, freeing students to concentrate on complex learning.	• Identify the knowledge, skills, and strategies that students already possess, and build the course around new challenges. Through assessment, identify students who have not mastered learning processes at Grade 12 levels and provide additional assistance and support.
• Students have a clearer self-understanding and have developed specialized interests and expertise. They need to connect what they are learning to the world outside the school. Chemistry must be seen as valuable and necessary.	• Use strategies that enhance students' metacognition. Encourage students to develop scientific skills through exploring areas of interest. Cultivate classroom experts and invite students with individual interests to enrich the learning experience of the class.

(continued)

* **Grade 12 Learners: Implications for Teachers:** Adapted from *Grade 12 English Language Arts: A Foundation for Implementation*.

Grade 12 Learners: Implications for Teachers (continued)	
Characteristics of Grade 12 Learners	**Significance for Grade 12 Teachers**
Psychological and Emotional Characteristics	
• It is important for Grade 12 students to see that their autonomy and emerging independence are respected. They need a measure of control over what happens to them in school.	• Provide choice. Allow students to select many of the resources they will explore and the forms they will use to demonstrate their learning. Collaborate with students in assessment. Teach students to be independent learners. Gradually release responsibility to students.
• Students are preparing for senior leadership roles within the school and may be more involved with leadership in their communities.	• Provide students with leadership opportunities within the classroom and with a forum to practise skills in public speaking and group facilitation.
• Students need to understand the purpose and relevance of practices, policies, and processes. They may express their growing independence through a general cynicism about authority and institutions.	• Use students' tendency to question social mores to help them develop critical thinking. Negotiate policies and demonstrate a willingness to make compromises. Use students' questions to fuel classroom inquiry.
• Grade 12 students have a clearer sense of identity than they had previously and are capable of being more reflective and self-aware. Some students are more willing to express themselves and disclose their thoughts and ideas.	• Provide optional and gradual opportunities for self-disclosure. Invite students to explore and express themselves through their work. Celebrate student differences.
Physical Characteristics	
• Many Grade 12 students have reached adult physical stature. Others, particularly males, are still in a stage of extremely rapid growth and experience a changing body image and self-consciousness.	• Be sensitive to the risk students may feel in public performances and increase expectations gradually. Provide students with positive information about themselves.
• By Grade 12, students are better able to sit still and concentrate on one learning task for longer periods, but they still need interaction and variety. They have a great deal of energy.	• Put physical energy to the service of active learning instead of trying to contain it. Provide variety; change the pace frequently; use kinesthetic learning experiences.
• Grade 12 students still need more sleep than adults, and may come to school tired as a result of part-time jobs or activity overload.	• Be aware that inertia or indifference may be the result of fatigue. Work with students and families to set goals and plan activities realistically so that school work assumes a higher priority.

(continued)

Grade 12 Learners: Implications for Teachers (continued)	
Characteristics of Grade 12 Learners	**Significance for Grade 12 Teachers**
Moral and Ethical Characteristics	
• Grade 12 students are working at developing a personal ethic, rather than following a prescribed set of values and code of behaviour.	• Explore the ethical meaning of situations in life and in scientific contexts. Provide opportunities for students to reflect on their thoughts in discussion, writing, or representation.
• Students are sensitive to personal or systemic injustice but are increasingly realistic about the factors affecting social change.	• Explore ways decision-making activities can effect social change, and link to the continuum of science, technology, society, and the environment.
• Students are shifting from an egocentric view of the world to one centred in relationships and community. They are able to recognize different points of view and adapt to difficult situations.	• Provide opportunities for students to make and follow through on commitments and to refine their interactive skills.
• Students are becoming realistic about the complexities of adult responsibilities but resist arbitrary authority.	• Explain the purpose of every learning experience. Enlist student collaboration in developing classroom policies. Strive to be consistent.
Social Characteristics	
• By Grade 12, certain individuals will take risks in asserting an individual identity. Many students, however, continue to be intensely concerned with how peers view their appearance and behaviour. Much of their sense of self is drawn from peers, with whom they may adopt a “group consciousness” rather than making autonomous decisions.	• Ensure that the classroom has an accepting climate. Model respect for each student. Use learning experiences that foster student self-understanding and self-reflection. Challenge students to make personal judgements about situations in life and in their natural environment.
• Adolescents frequently express identification with peer groups through slang, musical choices, clothing, body decoration, and behaviour.	• Foster a classroom identity and culture. Ensure that every student is included and valued. Structure learning so that students can interact with peers, and teach strategies for effective interaction.
• Crises of friendship and romance, and a preoccupation with relationships, can distract students from academics.	• Open doors for students to study personal relationships in science (for example, through biographies of scientists). Respect confidentiality, except where a student’s safety is at risk.
• Students begin to recognize teachers as individuals and welcome a personal connection.	• Nurture and enjoy a relationship with each student. Try to find areas of common interest with each one. Respond with openness, empathy, and warmth.

Fostering a Will to Learn: Creating Links between Language and Science

Experiences of intense involvement are optimal opportunities to teach engagement in learning, and teachers should try to ensure they happen frequently in the classroom. Not every learning task, however, can be intrinsically rewarding to every learner. Being a successful learner also requires a high degree of what Corno and Randi (1997) call "sustained voluntary effort"—an attitude expressed in committing oneself to less interesting tasks, persisting in solving problems, paying conscientious attention to detail, managing time, self-monitoring, and making choices between competing values, such as the desire to do well on a homework assignment and the desire to spend the evening with friends. The willingness to make this sustained effort constitutes motivation.
Motivation is a concern of teachers, not only because it is essential to classroom learning, but also because volition and self-direction are central to lifelong learning. Science courses seek to teach students how to interpret and analyze science concepts, and to foster the desire to do so. Motivation is not a single factor that students either bring or do not bring to the classroom. It is multi-dimensional, and individual, and often comprises both intrinsic and extrinsic elements. Students hold certain presuppositions about science learning that affect the way they learn. Teachers can promote certain attitudes and skills to facilitate students' engagement in each learning task, while recognizing and affirming entry-level abilities.
In considering how they can foster motivation, teachers may explore students' appreciation of the value (intrinsic and extrinsic) of learning experiences and their belief about their likelihood of success. Good and Brophy (1987) suggest that these two elements can be expressed as an equation; the effort students are willing to expend on a task is a product of their expectation of success and of the value they ascribe to success.

Expectancy	**x**	**Value**	**=**	**Motivation**
(the degree to which students expect to be able to perform the tasks successfully if they apply themselves)		(the degree to which students value the rewards of performing a task successfully)		

Teachers may, therefore, want to focus on ensuring students are able to succeed if they apply reasonable effort, and on helping students recognize the value of classroom learning experiences. The following chart provides teachers with suggestions for fostering motivation.

Fostering Motivation*	
Ways to Foster Expectations of Success	**Best Practice and Research**
• Help students to develop a sense of self-efficacy.	• Schunk and Zimmerman (1997) found that students who have a sense of self-efficacy are more willing to participate, work harder, persist longer when they encounter difficulties, and achieve at a higher level than students who doubt their learning capabilities. Teachers foster student self-efficacy by recognizing that each student can succeed, and communicating that belief to the student. Silver and Marshall (1990) found that a student's perception that he or she is a poor learner is a strong predictor of poor performance, overriding natural ability and previous learning. All students benefit from knowing that the teacher believes they can succeed and will provide the necessary supports to ensure that learning takes place. Teachers also foster a sense of self-efficacy by teaching students that they can learn how to learn. Students who experience difficulty often view the learning process as mysterious and outside their control. They believe that others who succeed in school do so entirely because of natural, superior abilities. It is highly motivating for these students to discover that they, too, can learn and apply the strategies that successful students use when learning.
• Help students to learn about and monitor their own learning processes.	• Research shows that students with high metacognition (students who understand how they learn) learn more efficiently, are more adept at transferring what they know to other situations, and are more autonomous than students who have little awareness of how they learn. Teachers enhance metacognition by embedding, into all aspects of the curriculum, instruction in the importance of planning, monitoring, and self-assessing. Turner (1997) found that teachers foster a will to learn when they support "the cognitive curriculum with a metacognitive and motivational one" (p. 199).
• Assign tasks of appropriate difficulty, communicating assessment criteria clearly, and ensuring that students have clear instruction, modelling, and practice so they can complete the tasks successfully.	• Ellis et al. (1991) found that systemic instruction helps students learn strategies they can apply independently (see Instructional Strategies, Section 2, p. 33).

(continued)

* **Fostering Motivation:** Adapted from *Grade 12 English Language Arts: A Foundation for Implementation.*

Fostering Motivation (continued)	
Ways to Foster Expectations of Success	**Best Practice and Research**
• Help students to set specific and realistic personal goals and to learn from situations where they do not attain their goals, and celebrate student achievements.	• Research shows that learning is enhanced when students set goals that incorporate specific criteria and performance standards (Foster, 1996; Locke and Latham, 1990). • Teachers promote this by working in collaboration with students in developing assessment (see Assessment in Grade 12 Chemistry [Section 3]; and Appendix 5).
• Offer choices.	• Intrinsic motivation is closely tied to students' self-selection of topics, texts, activities, and creative forms. Teachers may involve the students in the choice of a topic for thematic development. Support students in the search for learning resources that are developmentally appropriate and of high interest, and encourage students to bring the world views they value into the classroom. Self-selection allows students to build their learning on the foundation of their personal interests and enthusiasm.
• Set worthwhile academic objectives.	• Rather than asking students to execute isolated skills or perform exercises that are without context, embed instruction in meaningful events and activities that simulate real-world settings, and ensure that students share performances and products with a peer audience.
• Help students to learn about and monitor their own learning processes.	• In teaching specific learning strategies, focus on the usefulness of each strategy for making information meaningful, or for expressing ideas of importance to students. Emphasize the importance of science to the richness and effectiveness of students' lives, and de-emphasize external rewards and consequences such as marks.
• Ensure that scientific experiences are interactive.	• A community that encourages students to share their learning with each other values science. Teachers who model curiosity, enthusiasm, and pleasure in learning science-related concepts, and who share their experiences, foster motivation for scientific literacy.

Creating a Stimulating Learning Environment

A vital science class grows out of, and is reflected in, a stimulating and inviting physical environment. While the resources and physical realities of classrooms vary, a well-equipped science classroom offers or contains a variety of resources that help stimulate learning. It is helpful to involve students in the classroom design.

Ways to create a stimulating learning environment include the following:

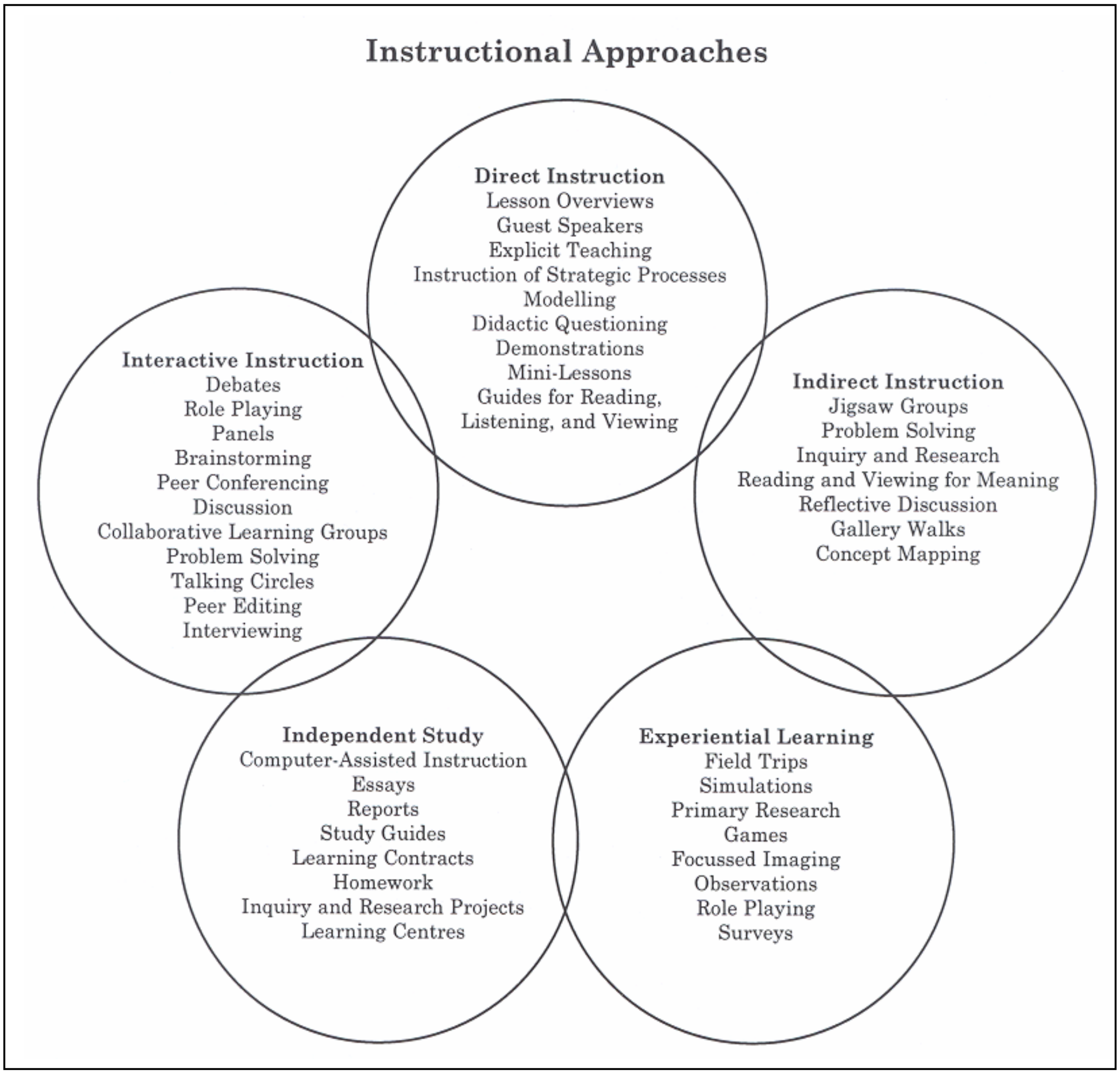
- FLEXIBLE SEATING ARRANGEMENTS: Use moveable desks or tables to design seating arrangements that reflect a student-centred philosophy and that allow students to interact in various configurations.

- A MEDIA-RICH ENVIRONMENT: Have a classroom library of books for self-selected reading. The classroom library may include science periodicals, newspaper articles, newsletters, Internet articles, science-fiction literature, and students' published work. It may also include a binder of student reviews and recommendations, and may be decorated by student-designed posters or book jackets. Classroom reference materials could include dictionaries/ encyclopedias of science, books of facts, software and CD-ROM titles, past exams collated into binders, and manuals.
- ACCESS TO ELECTRONIC EQUIPMENT: Provide access to a computer, television, video cassette recorder/DVD-Rom, and video camera, if possible.
- WALL DISPLAYS: Exhibit posters, Hall of Fame displays, murals, banners, and collages that celebrate student accomplishments. Change these regularly to reflect student interests and active involvement in the science classroom.
- DISPLAY ITEMS AND ARTIFACTS: Have models, plants, photographs, art reproductions, maps, newspaper and magazine clippings, fossils, musical instruments, et cetera, in your classroom to stimulate inquiry and to express the link between the science classroom and the larger world.
- COMMUNICATION: Post checklists, processes, and strategies to facilitate and encourage students' independent learning. Provide a bulletin board for administrative announcements and schedules.

Language Learning Connected to Science

Science curricula involve all aspects of language and literacy development. Halliday suggests that as students actively use the language arts, they engage in three kinds of language learning, which can be linked to broader scientific literacy (Strickland and Strickland, 1997).

- STUDENTS LEARN LANGUAGE: Language learning is a social process that begins at infancy and continues throughout life. Language-rich environments enhance and accelerate the process. Terminology-rich science has a role in new language development.
- STUDENTS LEARN THROUGH LANGUAGE: As students listen, read, or view, they focus primarily on making meaning from the text at hand. Students use language to increase their knowledge of the world.
- STUDENTS LEARN ABOUT LANGUAGE: Knowledge of language and how it works is a subject in and of itself; nevertheless, science as a discipline of inquiry relies on a particular use of language for effective communication. Consequently, students also focus on language arts and its role when applied to science. Scientific literacy learning is dynamic and involves many processes. The following graphic identifies some of the dynamic processes that form the foundation for effective literacy learning in science classrooms.



Ethical Issues

The development of topics within Grade 12 Chemistry should lead to issues and questions that go beyond the traditional curriculum. For example, medical biochemistry, or the implementation of international protocols related to the prospects of global climate change, raise questions of ethics, values, and responsible use of the products of the physical sciences. The environmental consequences of the industrial applications of chemistry, or the atmospheric chemistry of climate change, raise issues of considerable importance, as do the topics of nuclear waste disposal and weapons procurement. These are among the important issues that science is often called upon for advice. As students and teachers address these issues, they will naturally be drawn to the study of the underlying scientific concepts. Students should realize that science only provides the background for informed personal and social decisions, and that, as informed decision makers, they may have an impact on society and the world. Students of chemistry are not immune to the importance of these aspects of science in a modern, post-industrial world.

Some students and parent(s) may express concern because the perspectives of current science conflict with personal systems of belief. These individuals have a right to expect that science and the public educational system will respect those beliefs, though this does not preclude such issues arising in the classroom. Teachers should explain to students that science is one way of learning about the universe and our unique place embedded in it, and that other explanations, in addition to those of the traditional western sciences, have been put forth—particularly in the realm of cosmogony.

Diversity in the Classroom

Students come from a variety of backgrounds and have distinct learning requirements, learning and thinking approaches, and prior knowledge and experiences. Their depth of prior knowledge varies, reflecting their experiences inside and outside the classroom. Some entry-level knowledge held by students may be limited or incorrect, impeding new learning. For new learning to occur, it is important for teachers to activate prior knowledge, correct misconceptions, and encourage students to relate new information to prior experiences. Manitoba's cultural diversity provides opportunities for embracing a wealth of culturally significant references and learning resources in the Senior Years science classroom. Students from various backgrounds bring socially constructed meanings, references, and values to science learning experiences, as well as their unique learning approaches. As noted in *Senior Years Science Teachers' Handbook*, "To be effective, the classroom must reflect, accommodate, and embrace the cultural diversity of its students" (Manitoba Education and Training, 1997).

In addition, cultural influences can affect how students think about science: reasoning by analogy or by strict linear logic; memorization of specific correct responses or generalization; problem solving by induction or by deduction; or needing to learn through hands-on apprenticeship to gain one aspect of a skill before moving on to the next step (Kolodny, 1991). Cultural prohibitions permeate some societies; for example, values that discourage assertiveness, outspokenness, and competitiveness in some cultures can result in behaviour that can be interpreted as being indifferent, having nothing to say, or being unable to act decisively (Hoy, 1993; NRC, 1997). The problems engendered by these cultural differences are often beyond the ability of teachers of advanced courses to handle on their own. In many such cases, support from other members of the school staff is essential.

Learning Resources

Traditionally, the teaching of science in Senior Years has largely been a textbook-centred enterprise. The use of a single textbook as the sole resource for the teaching and learning of science severely restricts the development of knowledge, skills, and attitudes that are critical for today's students. Furthermore, it promotes the idea that all answers are enshrined in a textbook. The successful implementation of Grade 12 Chemistry depends on a resource-based learning approach, in which textbooks are used only as one of many reference sources. Research suggests that we should provide a wide range of learning resources for structuring teaching and learning experiences. These include human resources, textbooks, magazines/journals, films, audio and video recordings, computer-based multimedia resources, the Internet, and other materials.

Resources referenced in this curriculum include print reference material such as *Senior Years Science Teachers' Handbook: A Teaching Resource* (Manitoba Education and Training, 1997) and *Science Safety: A Kindergarten to Grade 12 Resource Manual for Teachers, Schools, and School Divisions* (Manitoba Education and Training, 1997). In addition, numerous articles from the chemistry education research community are recommended to teachers.

The choice of learning resources, such as text(s), multimedia learning resources (including video, software, CD-ROMs, microcomputer-based laboratory [MBL] probeware, calculator-based laboratory [CBL] probeware), and websites, will depend on the topic, the local situation, reading level of the students, background of the teacher, community resources, and availability of other materials. A concerted effort should be made to use appropriate learning resources from a wide variety of sources, as not all curricular outcomes can be achieved by using any one resource in the study of a particular topic.

To help teachers and principals select learning resources for Grade 12 and Grade 12 chemistry, Manitoba Education, Citizenship and Youth will release *Chemistry 30S and Chemistry 40S Learning Resources: Annotated Bibliography: A Reference for Selecting Learning Resources (2006).* This annotated bibliography is published online at:

<http://www.edu.gov.mb.ca/ks4/learnres/bibliographies.html>.

Using This Curriculum Document

Chemistry curricula in the past have been primarily focussed on presenting a breadth of knowledge (that is, a large amount of content) deemed essential, and with a focus on the mathematical manipulation of algorithms. While this curriculum continues to be concerned with students acquiring relevant knowledge and appropriate mathematical treatment of concepts, it is also concerned both with fostering the development of various skills (context-based process skills, decision-making skills, problem-solving skills, laboratory experimental skills, critical thinking skills, independent learning skills), and with effecting a change of viewpoint. A strong focus of Grade 12 Chemistry is to link science to the experiential life of the students.

By offering a multidisciplinary focus where appropriate, Grade 12 Chemistry provides a new set of foundations for fostering increased scientific literacy. The curriculum, consisting of 29 General Learning Outcomes (GLOs), each with a number of Specific Learning Outcomes (SLOs) linked to them, will build upon what students know and are able to do as a result of their studies in Kindergarten to Senior 2 Science (see Figure 6: *Kindergarten to Senior 2 Topic Chart*, Section 1, page 16).

Grade 12 Chemistry assumes **110** hours of instructional time, and is designed to include formal assessments, field excursions, and related co-curricular efforts.

Effective Teaching in Chemistry: What the Research Says to Teachers

Findings of Research on How Students Learn

A number of summaries of the instructional implications of recent research on learning have been prepared. The National Research Council report *How People Learn: Brain, Mind, Experience, and School: Expanded Edition* (Bransford et al., 2000) can be adapted and elaborated specifically for the study of chemistry. That report leads to the following implications for effective chemistry instruction.

1. **Effective teachers draw out and work with students' current understandings, including those understandings students bring with them to the course and those they develop as the course progresses.**

   There is an emerging consensus in science education research, including a substantial body of work specific to introductory chemistry, that, to be effective, instruction must elicit, engage, and respond substantively to student understandings (Champagne, Gunstone, and Klopfer, 1985; Clement, 1983; Hake, 1998; Hestenes, Wells, and Swackhamer, 1992; McDermott and Redish, 1999). There are now a number of examples of curricula and materials designed to support interaction with students' prior understandings, and there is evidence that these approaches can achieve progress in understanding that is not possible for most students with traditional methods.

2. **Effective teachers address students' metacognitive skills, habits, and epistemologies.**

   Students need to understand not only the concepts of chemistry, but also the nature of knowledge and learning (Hammer, 1995; Hewson, 1985; McDermott, 1991; Reif and Larkin, 1991; White and Frederiksen, 1998). Many students arrive at chemistry courses, including advanced-treatment courses such as Chemistry AP, expecting to learn by memorizing formulas disconnected from each other, as well as from the students' experiences of the physical world. Effective instruction challenges these expectations, helping students to see chemistry learning as a matter of identifying, applying, and refining their current understanding. Students learn to examine assumptions hidden in their reasoning; to monitor the quality and consistency of their understanding; to formulate, implement, critique, and refine models of physical phenomena; and to make use of a spectrum of appropriate representational tools. By the end of a chemistry course, students develop a rich sense of the coherent, principled structure of chemistry and are both able and inclined to apply those principles in unfamiliar situations. In short, effective instruction should work toward the objectives identified in the *Manitoba Foundations for Science Literacy*.

3. Effective teachers are sophisticated diagnosticians of student knowledge, reasoning, and participation.

How teachers respond to student thinking depends critically on what they perceive in that thinking, on what they interpret to be the strengths and weaknesses of the students' understanding and approach. Effective teachers continually gather information to support this ongoing assessment from several different sources: written work on assignments, tests, and quizzes; classroom discussions; and contact with students outside the classroom. They ask students to explain their reasoning throughout their work, particularly through the appropriate and measured use of differentiated instruction techniques. Upon gaining new insights into student understanding, effective teachers adapt their instructional strategies and assessments.

4. Effective teachers teach a smaller number of topics in greater depth, providing many examples in which the same concept is at work.

This is a common refrain in findings from education research, often expressed in the slogan "less is more." In part, this finding is an implication of the previous two: drawing out and working with student understandings and addressing metacognitive skills and habits all take time, and this necessitates a reduction in the breadth of coverage. Education research also suggests that coming to understand a concept requires multiple encounters in multiple contexts. This finding is reflected across innovations in this chemistry curriculum that have drawn on the "spiralling" approach fostered throughout all Kindergarten to Senior Years science in Manitoba.

Making Interdisciplinary Connections in the Chemistry Classroom

An important issue for a field as ancient as chemistry is how it adapts to the needs of society in a given place and time. The field of chemistry today faces a period of transition.

- A period in which technology and knowledge-based industries are the primary drivers of the national economy has begun.
- A period in which other areas of science, such as microbiology and genetics, will undergo rapid progress has also begun.
- The increasing availability, power, and sophistication of computational hardware and software will make possible novel quantitative descriptions of the physical universe. Society in general appears to be rapidly becoming more and more knowledge based. Enormous quantities of information are instantly available on ubiquitous computers.

Teachers of chemistry will need to be able to apply the body of knowledge developed within chemistry to totally new areas. In other words, physicists will be asked to become more interdisciplinary; they will have to apply their special knowledge and methods to problems that cross the boundaries of traditional disciplines.

On the other hand, the topics that possess several features that naturally allow students to begin to confront interdisciplinary issues are welcome, and align more closely to the new emphases outlined in the *Manitoba Foundations for Science Literacy*. First, there is the provision for interdisciplinary options (biomedical chemistry, historical chemistry, the nature of science as seen through chemistry, et cetera) that teachers may choose to create.

Collaborative group work of students creates its interdisciplinary dimension through ownership of a collaborative scientific investigation. Such projects can easily involve applying knowledge and methods from several different scientific fields. Increased interdisciplinary content could be added to chemistry courses by developing more contexts such as the biomedical chemistry unit mentioned above. Alternatively, the enriched chemistry course might choose to explore examples illustrating how fundamental physical principles apply to a wide variety of areas. For example, the elastic properties of DNA molecules might be used to discuss the range of validity of Hooke's law for spring forces. Biological cell membranes could be used to construct interesting examples of electrical potential differences and electric fields. In agreement with the National Research Council's *National Science Education Standards* (*NSES*) (1996), Manitoba Education and Youth encourages teachers to include some experiences with the interdisciplinary applications of chemistry when implementing the chemistry curriculum.

Unit Development in Chemistry

Grade 12 Chemistry is driven by specific learning outcomes that can be arranged in a variety of groupings. This design empowers teachers to plan appropriate learning experiences based on the nature of their students, school, and community. Teachers are encouraged to seek their own instructional design with the new curriculum, to share approaches and experiences with colleagues, and to use it to develop and extend student experiences and understandings in new ways.

Working with bigger ideas can allow for a more in-depth inquiry. Organizing around a problem or theme will generally present information in the context of real-world applications (Willis, 1992). For instance, the treatment of vector analysis or free-body diagrams—usually taught in isolation as discrete mastery skills—could be better served by presenting these concepts at the time when the context will demand their use. Throughout the year, provide students with opportunities to uncover concepts from among the sciences in a substantial way, and to make coherent connections among them to chemistry.

> Science deals with major themes in which people are already interested or can readily be interested: life and living things, matter, the universe, information, the 'made-world'. A primary reason, therefore, for teaching science to young people is to pass on to them some of this knowledge about the material world, simply because it is both interesting and important—and to convey the sense of excitement that scientific knowledge brings (Millar and Osborne, 1998).

For teachers adopting a “thematic” or “big ideas from chemistry” approach to organizing the course, choosing an effective theme is critical to the success of such a pathway. Involving students in the selection of a theme (or the important subcomponents of a compulsory topic) will encourage and motivate them by recognizing their interests.

A theme should:

- be broad enough for students to find personal areas of interest;
- promote learning;
- have substance and apply to the real world;
- have relevant materials readily available;
- be meaningful and age-appropriate;
- have depth;
- integrate across the disciplines of chemistry, biology, chemistry, and geo sciences; and
- fascinate students (Willis, 1992).

IMPLEMENTATION OF GRADE 12 CHEMISTRY

A View of Chemistry Education: Toward Modes of Representation

Ask your students to respond, in one sentence, to the question, “What is chemistry?” Responses tend to describe previous experiences with chemistry content: “chemistry is molecular motion,” or “chemistry is the study of energy and matter,” or “chemistry is like physics with lots of math in it” or, from an educator’s standpoint, “chemistry is an understanding of particulate representations not visible to us.” Other responses are more global: “chemistry is the study of the makeup of the universe,” or “chemistry is the science of all things.” The relationship of mathematics to chemistry is predominant; a common lament is “chemistry is math” or “chemistry is figuring out the simple things in everyday life in a mathematically complex way” at the Senior Years. These responses indicate that students see mathematics as *the* process of chemistry. Many see chemistry as an important aspect of their preparation for an uncertain future, but with a varying sense of what chemistry really is and what it could do for them.

What is chemistry? Although answers vary, a common theme exists if we consider the various branches of chemistry and the underlying principles. Chemistry can also be considered as including *particulate representations* in the world we perceive around us. However, those relationships are embedded in visual, social, and historical contexts—a set of lenses through which the relationships are perceived and acted upon. For instance, we contemplate “something interesting,” then build models to identify fundamental characteristics to determine how they interact and influence each other. From these relationships we are able to predict the behaviour of other “interesting things” that have the same or similar parameters. A major component of chemistry, then, is the study of relationships in a variety of different forms. What makes the study of chemistry so difficult for so many is that relationships can be represented in many different ways—and too often are shown in just one manifestation, the mathematical symbolic relationship.

The modes of representing relationships include the following:

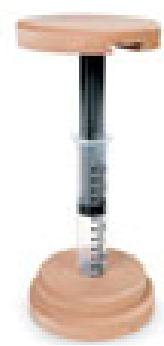
- visual mode
- numeric mode
- graphical mode
- symbolic mode

To facilitate teaching and learning, it is important to understand the various modes of representation and their relationship to each other.

The Modes of Representation

The Macroscopic (Visual) Mode

To illustrate these modes of representation, consider an example making use of the physical properties of gases under changes in pressure. Initially, a single book is placed on top of syringe apparatus (see illustration at right). If we



then enlarge the scope of the picture by adding other books, we can then perceive that a relationship is emerging relating the amount of mass added to the syringe (that is, compressing the gas within the syringe) and the amount of compression in the gas sample. This is what we would call the *macroscopic (visual)* mode of representing a relationship. Its basis is in the “real” world of sense perception and our associated perceptions of how this “world” operates.

In the **macroscopic mode,** we suggest a relationship between two variables and then test our hypothesis by observation and experimentation. In the present case, as the downward force increases wit the addition of more books, the syringe depresses in some easily observed proportional manner. Sometimes, we can even determine the exact relationship. In this case, we can place a hypothetical “straight edge” to line up in a straight line across the syringes, and certainly this does seem to indicate that there is a predictable relationship.

(GRAPHIC TO BE INSERTED HERE)

The visual mode of representation embodies more than conjecture and observation. It incorporates critical and creative thinking as we build and modify models of nature that act as a foundation for our investigations. The “real” world is conceptualized by a set of guiding assumptions we imagine to be true. We may internalize a model to aid this conceptualization, and then we test this model using experiments. A successful model has explanatory and predictive capabilities. A model may incur discrepant events, which may force us to reconsider and modify our model. Our model may be falsified, in which case we abandon the model in search of a more complete and accurate model. For instance, the model of electric charge provides a foundation for the examination of electric phenomena. Historically, the fluid and particle models of charge accounted for experimental observations. However, as our ideas about the structure of matter evolved, the particle model provided a more reliable, predictive, and robust explanatory model.

Although we can make some general descriptions of relationships (e.g., as force increases, stretch increases), we cannot always determine an exact relationship using the visual mode of representation. Therefore, we *quantify* the characteristics and compare the numbers. This is called the *numeric* mode of representation and is outlined in the next section.

Numerical Mode

In the numeric mode of representation, we *operationally define* fundamental properties and use measurement to collect data. In the case here, the pressure exerted on the gas is operationally defined as "changes in the position of the syringe" and is something we can readily see with the eyes. If there is no pressure applied, we see no change in the position of the syringe, and greater force implies greater pressure exerted on the air within the syringe. We can then examine the data to determine an exact relationship. The numerical mode dictates an understanding of proportioning and numeric patterns (e.g., if pressure (P) doubles, volume (V) is halved, and if P triples, V is reduced to a third of original volume, and so on). This suggests a direct proportion, and we can then formulate a representative "law" describing the predictable behaviour of confined gas samples or other phenomena of interest. However, in most cases that students and researchers are involved in, the collection of data results in systematic errors. Determining the relationship by simple inspection of the data can be very difficult. A picture, however, is worth a thousand numbers to us. Graphing the data usually gives a clearer picture of the relationship. It could be looked upon, for students, as a preparation for examining closely a "picture of the numbers" (the graph). The following two data tables are examples of numerical modes that are of importance to us at the Grade 12level – to identify a *direct relationship* (force and spring stretch) and an *inverse relationship* (volume and pressure in a gas sample).

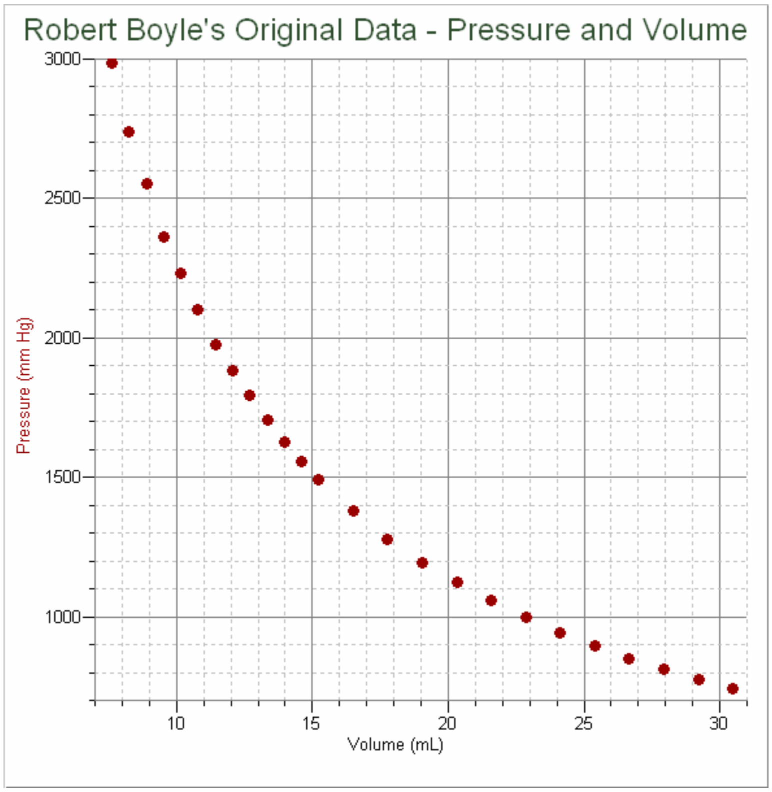
Volume and Pressure in a Gas

Volume	Pressure
mL	mmHg
30.5	739.8
20.3	1122.4
15.2	1493.8
10.2	2232.0

Graphical Mode

The graphical mode of representation is a mathematical picture of the relationship. Fortunately, there are a limited number of pictures one needs to know to determine relationships. In fact, at the introductory Grade 12 chemistry level, it is only necessary to know three pictures that derive from mathematical relationships: a straight line, a power curve, and an inverse curve. By adjusting the data to "straighten the curve," we can determine the exact relationship and formulate a law that can be represented in a symbolic manner.

For our purposes here, there can be no better example of the power of mathematical modelling than that from the relationship between the volume of a gas sample and the pressure it exerts on the walls of a container. We, of course, know this as ***Boyle's Law***, but it is instructive to view this from the point of view of students and our discussion here of **modes of representation**. Below is a graphical representation of numerical data from a fictitious student lab experience based on Robert Boyle's original data:



We would expect two things to arise from a discussion of this "picture". First, the relationship is inverse in some way (as one variable gets larger, the responding variable gets smaller). Second, the inverse behaviour is not "one to one", that is, it is not a linear relationship. We cannot expect that either volume or pressure can increase or decrease indefinitely in realistic terms. In order to "tease out", or model the physical law that explains this behaviour of gases under pressure, students are instructed in the techniques for *curve straightening* at Senior 3. This technique directly links the *graphical* and *symbolic* modes of representation.

Let's see how this is accomplished. Our initial mathematical model states, using the present example with gases, that some sort of inverse relationship exists between volume and pressure. Expressing this as follows is a good starting point:

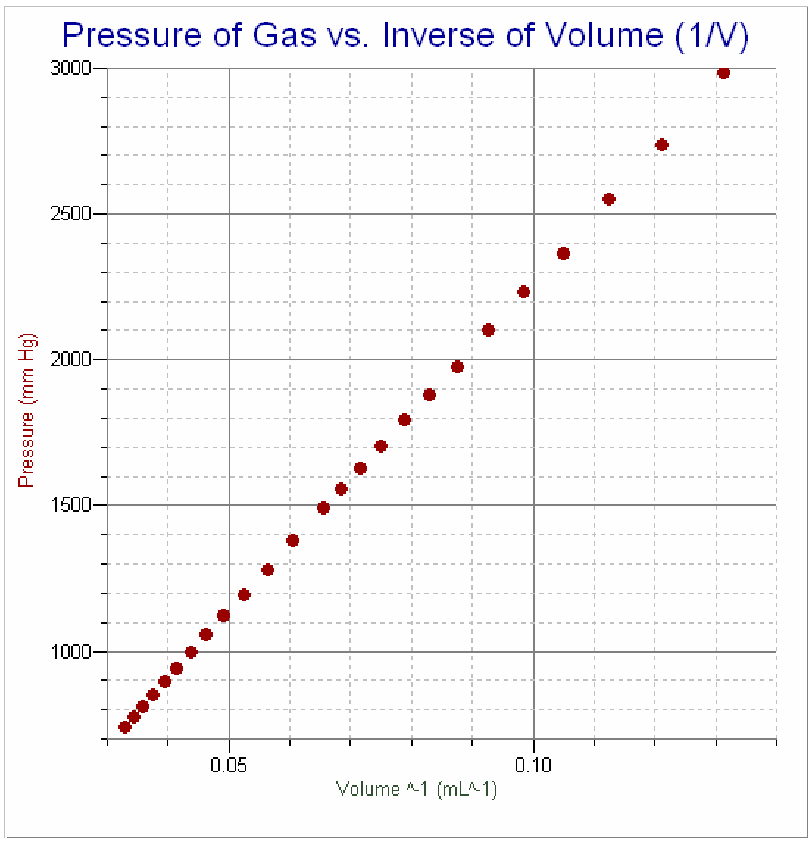
"Pressure goes down as Volume goes up"

$$P \; \alpha \; 1/V$$

or

$$P = k \bullet V^{-1}$$

The implication is that if we re-plot that data, but this time plot the *inverse of volume* against pressure, a new relationship should become visible. Here it is:



Symbolic Mode

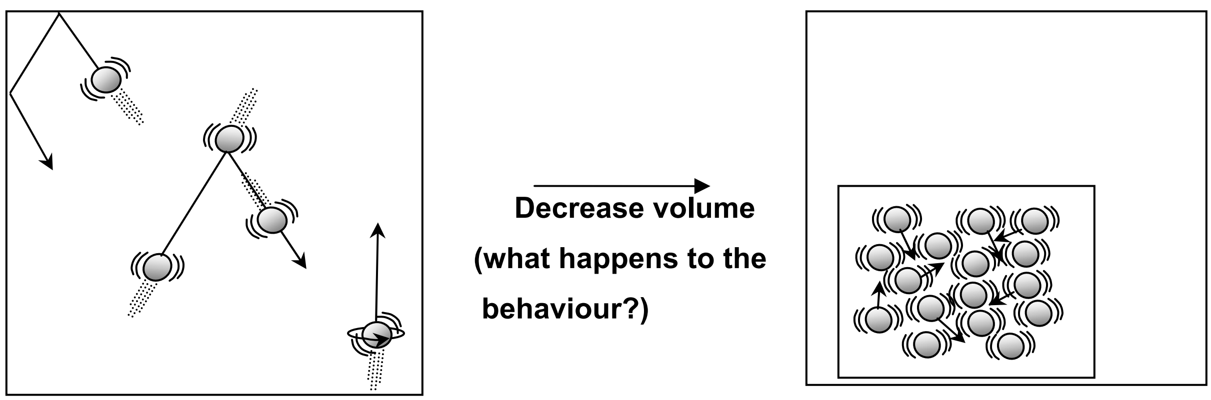
The fourth mode of representation is the *symbolic mode*. To continue with our example using Boyle's Law, we represent the relationship between pressure and volume of a gas as an *algebraic* relationship, which can be applied to other physical events that are similar in nature. When we look again at the last graph plotting the inverse of volume with pressure, it is clearly evident that a direct relationship exists between these two quantities. It would be very easy to determine a line of "best fit" for this graph, determine the slope of that line, and close off the discussion with the statement of a fundamental physical law.

If $P = k \bullet V^{-1}$, then $P \bullet V$ = a constant (k)

We then can state Boyle's Law as the product of pressure and volume as being a constant....

Therefore, thus far, we have represented relationships in four different modes: visual, numeric, graphical, and symbolic. In our model of chemistry education, students should be afforded the opportunity to function in each mode of representation to demonstrate growing understanding and mastery of these modes conceptually. Now, we will discuss a *fifth mode of representation* – PARTICULATE representations.

Throughout this course, students will regularly involve themselves with modelling chemical phenomena. This will include building ball-and-stick models, using software simulations, or drawing pictures of events that are occurring at the nanometre scale and are beyond our spatial constraints. For instance, we could illustrate the gas sample featured in this discussion in this manner:



The Importance of the Modes of Representation

It is easy to become caught up in a single mode of representation, especially the symbolic mode, when teaching and learning chemistry. Students often complain about the number of calculations in their chemistry course, or question their purpose. They dutifully memorize equations and notation, learn to substitute for variables, and arrive at numeric solutions. Students and teachers can easily become trapped exclusively within the symbolic mode of representation. Instruction using the symbolic mode is easy because little or no preparation is required. The teacher, already grounded in mathematical principles, only needs to derive an equation algebraically. This "out of context" treatment of relationships between the physical/conceptual (i.e., visual mode variables) and the symbolic presents tremendous difficulties for most students, including those students who are apparently mathematically competent.

Meaningful connections between the symbolic and physical/conceptual modes are difficult to make in a de-contextualized setting. Many teachers, whose own instruction in chemistry may have been primarily in the symbolic mode, may never have mediated their own conceptual difficulties. Students taught exclusively in the symbolic mode often know how to arrive at “cookbook” answers, but they rarely understand the chemistry or retain the concepts. In fact, their difficulties rarely focus on chemistry. Confusion appears because of notation, similar types of equations, various algebraic representations of formulas, and calculations. As soon as physical concepts are necessary, as in word problems beyond the “plug and slug” variety, success rates decrease dramatically. Research in chemistry education indicates that many advanced students experience difficulties when operating in the physical/conceptual domain, but do calculations with apparent ease and success. This, of course, may not be surprising if students’ instruction has been almost exclusively in the symbolic mode of representation.

Students need to develop their understanding of relationships more completely, and develop skills in each mode of representation. Students should be able to transfer between modes both fluidly and with facility. Moving through the modes is not necessarily done in consecutive order. A “real scientist” can begin investigations in any mode and transfer easily through any combination of modes. Students who demonstrate a complete understanding of physical/conceptual relationships should be able to move from mode to mode in any order.

While fluency with the modes of representation provides a solid foundation for chemistry education, it is, of itself, not complete when portraying the nature of scientific activity. Albert Einstein, while developing his theory of relativity, conceptualized an hypothesis and then deduced a series of laws symbolically from a set of fundamental assumptions about time and space. He left it to others to observe, then refute or confirm his propositions. Historical perspectives, and an understanding of the nature of science, will move students toward a more philosophically valid treatment of chemistry.

Summing up the Modes of Representation for Grade 12 Chemistry Teachers

- **Visual:** Encourage students to discuss the representations they see and experience.
- **Numeric:** Use student-generated measurements—always in the context of activities.
- **Graphical:** Carefully plot graphs; get the "picture of the numbers," not "this is a picture of the world."
- **Symbolic:** Emphasize the concept first, and then initially apply formulas as word definitions. Only then work "type" problems using formulas. Ideally, formulas are memorized only in certain instances.
- **Particulate:** Make use of physical models that explain or illustrate the invisible world of molecular structure and behaviour often. Attempt to connect physical phenomena with the underlying micro-scale movements of *particles*

Toward an Instructional Philosophy in Chemistry

Teaching Grade 12 Chemistry with a focus on both content and processes should naturally allow for the use of a variety of instructional strategies. These strategies include the collection and analysis of data from both laboratory and field work, group and individual instruction, a diversity of questioning techniques, decision making, problem solving, design process activities, and a resource-based approach to learning. Senior Years science programming should foster critical thinking skills and promote the integration of knowledge and application of facts to real-life situations. Scientific concepts from other Senior Years science courses may become part of the subject matter as the Grade 12 Chemistry course develops in the classroom. This is a valuable and useful means of reinforcing and validating those concepts as having relevant and contextual applications.

In general, chemistry is, in part, a way of thinking that has rules for judging the validity of answers applicable to everyday life. It can be portrayed as intense human activity, full of trial and error that is influenced by cultural priorities and humanistic perspectives. The myth of total objectivity that often permeates scientific dialogue also needs to be exposed and discussed. Among the natural sciences, "scientific truth" is no longer viewed as an objective reality awaiting discovery; rather, it is placed in the context of something always to be sought. In recognition of the tentative nature of current knowledge claims, "scientific truth" is not a goal that can be reached in absolute terms, but can remain as one of the hallmarks of the traditions of scientific practice.

Encourage students to make distinctions between what is observable and testable, as well as the abstract deductions, models, and themes that derive from evolving scientific research and thinking.

Conceptual knowledge in science can also be integrated with principles from other disciplines. Social, historical, and political implications, if included, provide an opportunity for students to develop a facility to communicate ideas effectively through verbal and written expression. Finally, students could be provided with an opportunity to develop an awareness of the options available to them for careers and vocations in the wide diversity of sciences.

Grade 12 Chemistry, as a component of young people's whole educational experience, will assist in preparing them for a full and satisfying life in the 21st century. This course will sustain and develop the curiosity of young people about the natural world around them, and build up their confidence in their ability to inquire into its behaviour, now and in the future. It seeks to foster a sense of wonder, enthusiasm, and interest in science so that young people feel confident and competent to engage with everyday scientific and technological applications and solutions. As students study a range of topics through various sub-disciplines of chemistry, they will acquire a broad, general understanding of the important ideas and explanatory frameworks of the field as a whole, including the procedures of scientific inquiry that have had a major impact on our material environment and on our culture. They will develop an appreciation for why these ideas are valued and the underlying rationale for decisions that they may wish, or be advised, to take in everyday contexts, both now and in later life. They will be able to understand, and respond critically to, media reports of issues with a science (particularly a chemistry-related) component. They will feel empowered to hold and express a personal point of view on issues with a science component that enter the arena of public debate, and perhaps to become actively involved in some of these issues (Millar and Osborne, 1998, p. 12).

Results-Based Learning

In results-based learning, the programming focus is on what students know and can do, rather than on what material is "covered." The learning outcomes are an elaboration of the knowledge, strategies, and skills and attitudes expected of each Grade 12 Chemistry student. All programming decisions are directed toward addressing the gap between the students' present level of performance and the performance specified in the learning outcomes.

Bridging the Gap between
Student Performance and the Prescribed Learning Outcomes

Present Level of Student Performance	Programming Decisions	Grade 12 Student Learning Outcomes
• Instructional Strategies • Materials and Resources • Assessment Tools and Strategies		

The student learning outcomes are not taught separately or in isolation. Nor are they taught consecutively in the order in which they appear in the curriculum documents. Most lessons or units draw on knowledge, strategies, and skills and attitudes addressed in several or all general learning outcomes. In the process of planning, teachers are encouraged to identify the learning outcomes they intend to assess, and link all assessment to the specific learning outcomes.

In implementing results-based curricula, experienced teachers may find that they use many of the instructional strategies and resources they have used previously. However, the nature of results-based learning will reshape their programming in several ways:

- Planning is ongoing throughout the semester or year because instruction is informed by learning requirements that become evident through continuous assessment.
- Some learning outcomes, especially skills and attitudes outcomes, are addressed repeatedly in different ways throughout the school semester or year. As students develop new scientific knowledge, strategies, and skills and attitudes, they need to practise and refine those they have previously experienced.

Varied Instructional Approaches

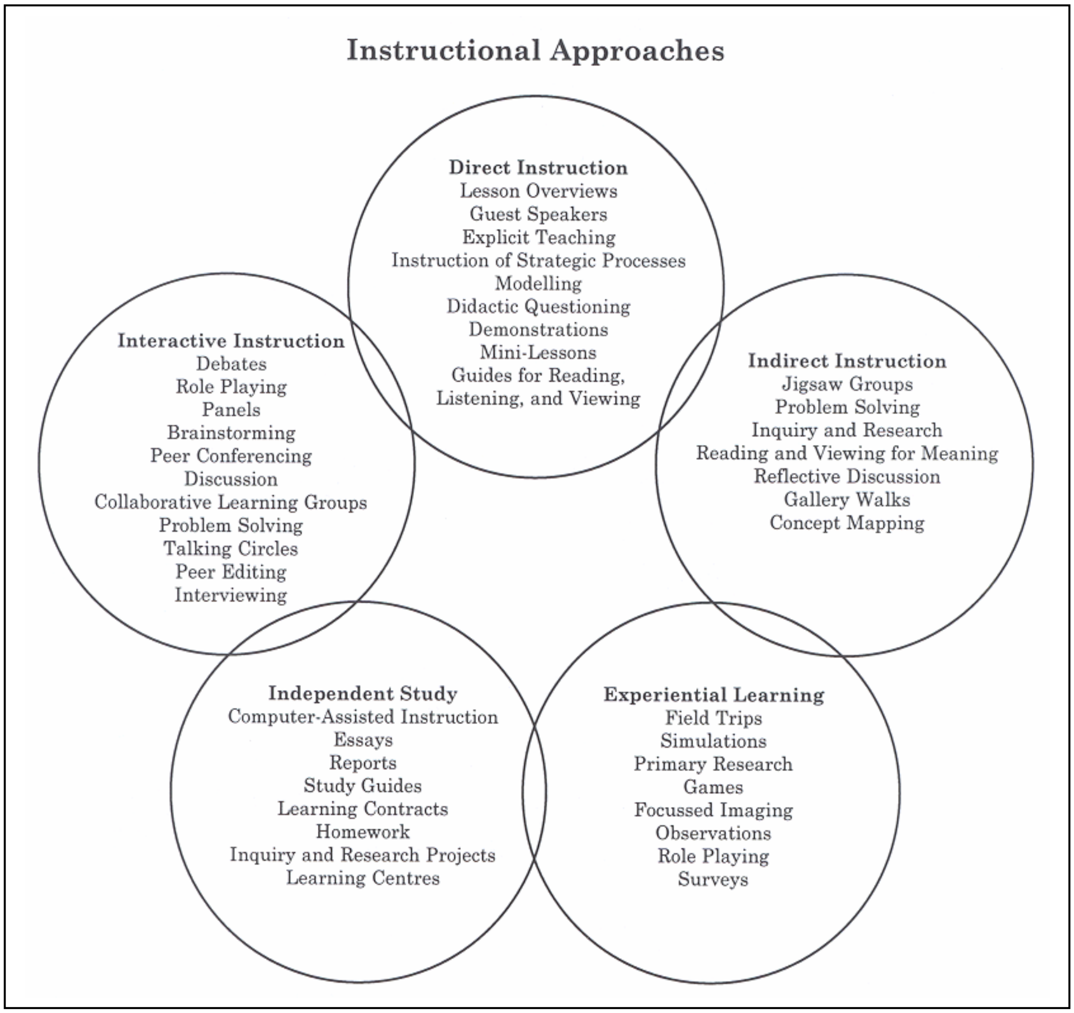
Teachers wear a number of different "pedagogical hats," and change their teaching style relative to the cognitive gains, attitudes, and skills demanded of the task at hand. In planning instruction for Grade 12 Chemistry, teachers may draw upon a repertoire of instructional approaches and methods and use combinations of these in each unit and lesson. Many suggestions are contained in this document.

Instructional approaches may be categorized as:

- direct instruction;
- indirect instruction;
- experiential learning;
- independent study; and
- interactive instruction.

Most teachers draw from all these categories to ensure variety in their classroom learning experiences, to engage students with various intelligences and a range of learning approaches, and to achieve instructional goals.

The following diagram displays instructional approaches and suggests some examples of methods within each approach. Note that the approaches overlap.



Instructional Approaches: Adapted from *Instructional Approaches: A Framework for Professional Practice.*

Instructional Approaches

In selecting instructional approaches and methods, teachers consider which combination will assist students in achieving the learning outcomes targetted for a particular lesson or unit. Teachers consider the advantages and limitations of the approaches and methods, as well as the interests, knowledge, and skills and attitudes of their students. Some of these elements are represented in the following chart.

Instructional Approaches: Roles, Purposes, and Methods				
Instructional Approaches	**Roles**	**Purposes/Uses**	**Methods**	**Advantages/ Limitations**
Direct Instruction	• Highly teacher-directed • Teacher ensures a degree of student involvement through didactic questioning	• Providing information • Developing step-by-step skills and strategies • Introducing other approaches and methods • Teaching active listening and note making	Teachers: • Explicit teaching • Lesson overviews • Guest speakers • Instruction of strategic processes • Lecturing • Didactic questioning • Demonstrating and modelling prior to guided practice • Mini-lessons • Guides for reading, listening, and viewing	• Effective in providing students with knowledge of steps of highly sequenced skills and strategies • Limited use in developing abilities, processes, and attitudes for critical thinking and interpersonal learning • Students may be passive rather than active learners
Indirect Instruction	• Mainly student-centred • Role of teacher shifts to facilitator, supporter, resource person • Teacher monitors progress to determine when intervention or another approach is required	• Activating student interest and curiosity • Developing creativity and interpersonal skills and strategies • Exploring diverse possibilities • Forming hypotheses and developing concepts • Solving problems • Drawing inferences	Students: • Observing • Investigating • Inquiring and researching • Jigsaw groups • Problem solving • Reading and viewing for meaning • Reflective discussion • Concept mapping	• Students learn effectively from active involvement • Allows for high degree of differentiation and pursuit of individual interests • Teacher requires excellent facilitation and organizational skills • Focussed instruction of content and concepts may be difficult to integrate

(continued)

Instructional Approaches: Adapted from *Grade 12 English Language Arts: A Foundation for Implementation*.

Instructional Approaches: Roles, Purposes, and Methods (continued)				
Instructional Approaches	**Roles**	**Purposes/Uses**	**Methods**	**Advantages/ Limitations**
Interactive Instruction	• Student-centred • Teacher forms groups, teaches and guides small-group skills and strategies	• Activating student interest and curiosity • Developing creativity and interpersonal skills and strategies • Exploring diverse possibilities • Forming hypotheses and developing concepts • Solving problems • Drawing inferences	Students participating in: • Discussions • Sharing • Generating alternative ways of thinking and feeling • Decision making • Debates • Role playing • Panels • Brainstorming • Peer conferencing • Collaborative learning groups • Problem solving • Talking circles • Interviewing • Peer editing	• Student motivation and learning increase through active involvement in groups • Teacher's knowledge and skill in forming groups, instructing, and guiding group dynamics are important to the success of this approach • Effective in assisting students' development of life skills in cooperation and collaboration
Experiential Learning	• Student-centred • Teacher may wish to design the order and steps of the process	• Focussing on processes of learning rather than products • Developing students' knowledge and experience • Preparing students for direct instruction	Students participating in: • Activities • Field trips • Simulations • Primary research • Games • Focused imaging • Role playing • Surveys • Sharing observations and reflections • Reflecting critically on experiences • Developing hypotheses and generalizations in new situations	• Student understanding and retention increase • Hands-on learning may require additional resources and time
Independent Study	• Student-centred • Teacher guides or supervises students' independent study, teaches knowledge, skills, and strategies that students require for independent learning, and provides adequate practice	• Accessing and developing student initiative • Developing student responsibility • Developing self-reliance and independence	Students participating in: • Inquiry and research projects • Using a variety of approaches and methods • Computer-assisted instruction • Essays and reports • Study guides • Learning contracts • Homework • Learning centres	• Students grow as independent, lifelong learners • Student maturity, knowledge, skills and strategies are important to success • Student access to resources is essential • Approach may be used flexibly (it may be used with individual students while other students use other approaches)

Phases of Learning

When preparing instructional plans and goals, many teachers find it helpful to consider three learning phases:

- activating (preparing for learning);
- acquiring (integrating and processing learning); and
- applying (consolidating learning).

These phases are not entirely linear but are a useful way of thinking and planning. A variety of activating, acquiring, and applying strategies are discussed in *Success for All Learners: A Handbook on Differentiating Instruction* (Manitoba Education and Training, 1996).

Activating (Preparing for Learning)

One of the strongest indications of how well students will comprehend new information is their prior knowledge of the subject. Some educators observe that more student learning occurs during this phase than at any other time. In planning instruction and assessment, teachers develop student learning experiences and select strategies for activating their students' prior knowledge. Using these activating strategies, the learning experiences then provide information about the extent of students' prior knowledge of the topic to be studied, their knowledge of and familiarity with the context in which that knowledge was acquired, and their knowledge of and proficiency in applying skills for learning.

Learning experiences that draw on students' prior knowledge:

- help students relate new information, skills, and strategies to what they already know and can do (e.g., if a text includes unfamiliar vocabulary, students may not recognize the connection between what they know and the new material being presented);
- allow teachers to recognize misconceptions that might make learning difficult for students;
- allow teachers to augment and strengthen students' knowledge base when students do not possess adequate prior knowledge and experience to engage with new information and ideas;
- help students recognize gaps in their knowledge; and
- stimulate curiosity and initiate the inquiry process that will direct learning.

Acquiring (Integrating and Processing Learning)

In the second phase of learning, students engage with new information and integrate it with what they already know, adding to and revising their previous knowledge. Part of the teacher's role in this phase is to present this new information or to help students access it from various resources.

Since learning is an internal process, however, facilitating learning requires more of teachers than simply presenting information. In the acquiring phase, teachers instruct students in strategies that help them make meaning of information, integrate it with what they already know, and express their new understanding. In addition, teachers monitor these processes to ensure that learning is taking place, using a variety of instruments, tools, and strategies such as observations, conferences, and examination of student work.

In practice, within an actual lesson or unit, the acquiring phase of learning may include a series of steps and strategies, such as:

- setting the purpose (e.g., discrepant events, lesson overviews, learning logs, admit slips);
- presenting information (e.g., lab demonstrations, guest speakers, mini-lessons, active reading);
- processing information (e.g., note making, group discussions, journals, visual representations);
- modelling (e.g., role-playing, demonstrations); and
- checking for understanding (e.g., quizzes, informal conferences).

Applying (Consolidating Learning)

New learning that is not reinforced is soon forgotten. The products and performances by which students demonstrate new learning are not simply required for assessment; they have an essential instructional purpose in providing students with opportunities to demonstrate and consolidate their new knowledge, skills and strategies, and attitudes. Students also need opportunities to reflect on what they have learned and to consider how new learning applies to new situations. By restructuring information, expressing new ideas in another form, or integrating what they have learned in science with concepts from other subject areas, students strengthen and extend learning.

To ensure that students consolidate new learning, teachers plan various learning experiences involving:

- reflection (e.g., journals, exit slips);
- closure (e.g., sharing of products, debriefing on processes); and
- application (e.g., inquiry, design process).

Differentiating Instruction

How can Senior Years science teachers meet each student's learning requirements and still make learning experiences challenging and meaningful for all? One way to help all students achieve the prescribed student learning outcomes is to differentiate the instructional strategies. Grade 12 Chemistry makes reference to a variety of field-validated strategies for differentiating instruction. Most have been taken from the support document *Senior Years Science Teachers' Handbook* (Manitoba Education and Training, 1997).

Through differentiating instruction, teachers can:

- activate students' prior knowledge;
- accommodate multiple intelligences and the variety of learning and thinking approaches;
- help students interpret, apply, and integrate information;
- facilitate the transfer of knowledge, skills, and attitudes to students' daily lives; and
- challenge students to realize academic and personal progress and achievement.

Differentiating instruction does not mean offering different programming to each student. Classroom experiences can be differentiated by offering students choices and by varying instructional and assessment strategies to provide challenging and effective learning experiences for all.

Promoting Strategic Learning

Many of the tasks science students perform are problem-solving tasks, such as finding sources of information for an inquiry project, making meaning of a difficult text, or organizing a body of information. To solve problems, students require a strategic mindset; when confronted with a problem, students survey a number of possible strategies, select the one that seems likely to work best for the situation, and try an alternative method if the first one does not produce results.

Strategic learners in the sciences need to have not only a strategic mindset, but also a repertoire of strategies for making meaning, for processing information, and for expressing ideas and information effectively. Whereas skills are largely unconscious mental processes that learners use in accomplishing learning tasks, strategies are systematic and conscious plans, actions, and thoughts that learners select or invent and adapt to each task. Strategies are often described as "knowing what to do, how to do it, when to do it, and why it is useful."

Scaffolding: Supporting Students in Strategic Learning

Many scientific tasks involve a complex interaction of skills. The most effective way to learn, however, is not by breaking down the tasks into manageable parts and teaching the skills separately and in isolation. In fact, this approach may be counterproductive. Purcell-Gates (1996) uses the analogy of learning to ride a bicycle, a skill that requires children to develop an intuitive sense of balance while also learning to pedal and steer. Children do not learn to ride a bicycle by focussing on only one of these skills at a time. Instead, they observe others who can ride a bicycle successfully, and then make an attempt themselves. In the early stages of learning to ride, a child counts on someone to provide support—to hold the bicycle upright while the child mounts, to keep a hand on the seat to stabilize the bicycle for the first few metres, and to coach and encourage. Gradually, these supports are withdrawn as the rider becomes more competent. Eventually, the process becomes automatic, and the rider is no longer aware of the skills being performed.
Providing this sort of support in teaching is called "scaffolding," based on the work of Wood, Bruner, and Ross (1976). Teachers scaffold by:

- structuring tasks so that learners begin with something they can do;
- reducing the complexity of tasks;
- calling students' attention to critical features of the tasks;

- modelling steps; and
- providing sufficient guided and independent practice.

In a sense, each learning strategy is an external support or scaffold. At first, working with a new strategy may be challenging and the main focus of students' attention. Eventually, students use the strategy automatically and rely on it as a learning tool. Students gradually internalize the process of the strategy. They begin to adjust and personalize the process and to apply the thinking behind the strategy automatically.

In strategic instruction, teachers observe and monitor students' use of a strategy for a time, intervening where necessary. Students vary in the length of time they require scaffolding. In this respect, strategic instruction is also a useful tool for differentiation. Struggling learners may work with simplified versions of a strategy, and they may continue to use the supports of a strategy (for example, a graphic organizer for laboratory reports) after other students have internalized the process.

Strategic instruction works best when teachers pace the instruction of new strategies carefully (so that students have time to practise each one), and when they teach a strategy in the context of a specific task of relevant scientific experience.

Instructional Strategies

The following outlines instructional strategies that may be used with Grade 12 Chemistry. The strategies are referenced in the Suggestions for Instruction column of this document.

- **Journal Writing**
  - — Science journal writing allows students to explore and record various aspects of their experiences in science class. By sorting out their thoughts on paper or thinking about their learning (metacognition), students are better able to process what they are learning.
- **Class Discussion**
  - — Discussions may be used in a variety of ways. They may spark interest in a topic or learning outcome, activate prior knowledge by inviting speculation on why certain events occur, or generate ideas for solutions to problems.

- **Prior Knowledge Activities**
  — Students learn best when they are able to relate new knowledge to what they already know. Brainstorming, KWL charts, and Listen-Think-Pair-Share (see *Senior Years Science Teachers' Handbook*) are just a few of the strategies that may be used to activate and assess students' prior knowledge.

- **Student Research/Reports**
  — Learning projects that involve student research are one of the most effective ways to individualize instruction in a diverse classroom. These learning activities provide students with the opportunity to develop their research skills as they gather, process, and evaluate information.

- **Teacher/Student Demonstration**
  — Demonstrations, such as discrepant events, may be used to arouse student interest and allow for visualization of phenomena. Demonstrations can activate prior knowledge and generate discussion about learning outcomes.

- **Visual Displays**
  — When students create visual displays, they make their thinking visible. Generating diagrams, posters, or models provides students with the opportunity to represent abstract information in a more concrete form.

- **Collaborative Teamwork**
  — Instructional strategies, such as the Jigsaw or Roundtable (see *Senior Years Science Teachers' Handbook*), encourage students to learn from one another and to develop teamwork skills. The use of cooperative learning activities may lead to increased understanding of content and improved thinking skills.

- **Laboratory Activities**
  — Laboratory activities, whether student- or teacher-designed, provide students with the opportunity to apply their scientific knowledge and skills related to a group of learning outcomes. Students appreciate the hands-on experience of doing science.

- **Debates**
  — Debates draw upon students' own positions on STSE issues. When carefully structured, debates may be used to encourage students' consideration of societal concerns and the opinions of others, and to improve their communication and research skills.

- **Community Connection**
  — Field trips and guest speakers may provide students with the opportunity to see science applied in their community and local natural environments.

- **Webquests**
  - — A Webquest is an inquiry-oriented activity in which most or all the information used by learners comes from resources on the Internet. Webquests are designed to use learners' time well, to focus on using information rather than looking for it, and to support learners' thinking at the levels of analysis, synthesis, and evaluation.
- **Problem-Based Learning (PBL)**
  - — PBL is a curricular design that centres on an authentic problem. Students are assigned roles and presented with a problem that has no single, clear-cut solution. Students acquire content knowledge as they work toward solving the problem.