Chemistry

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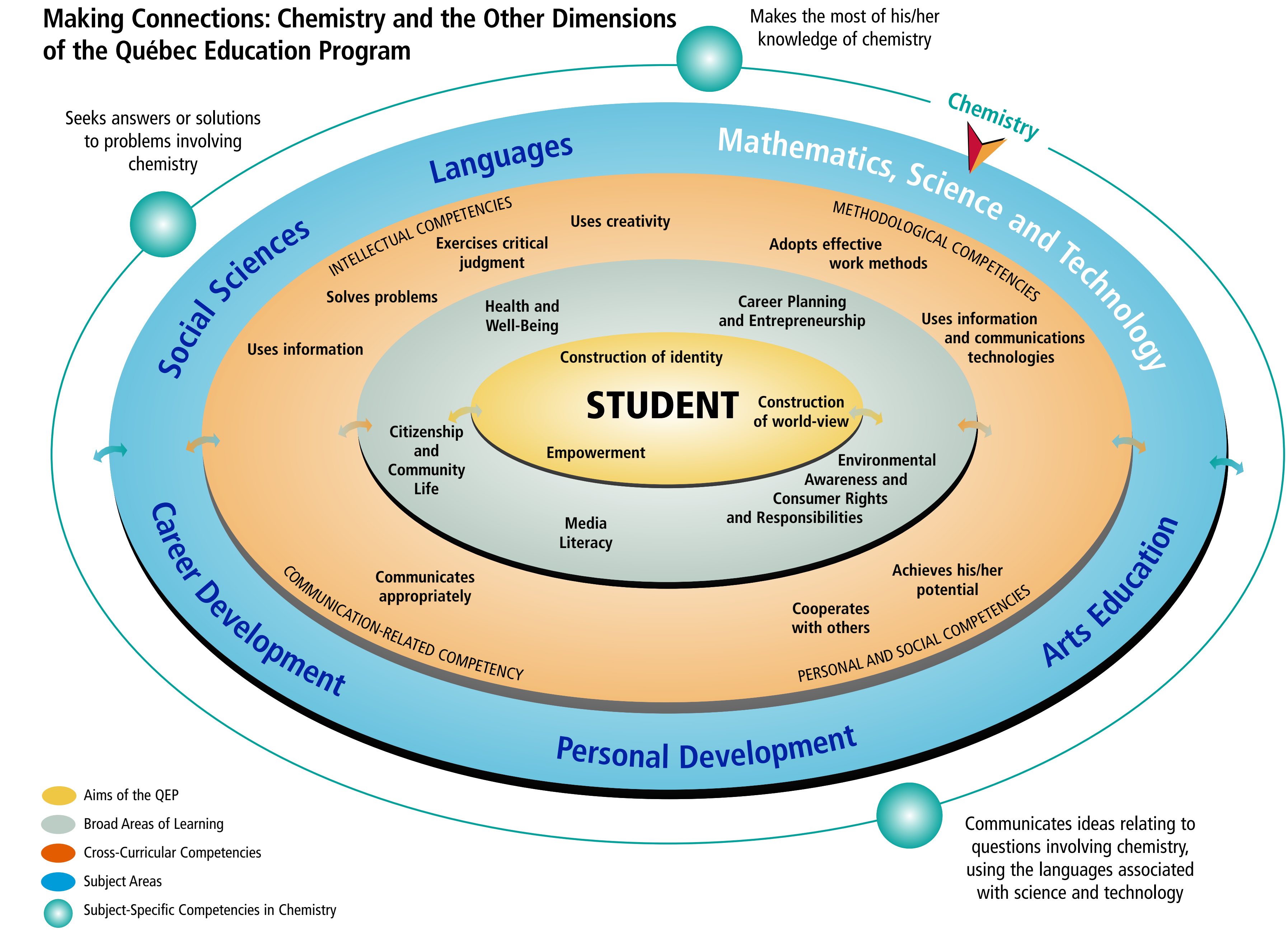
Making Connections: Chemistry and the Other Dimensions of the Québec Education Program



Introduction to the Chemistry Program

Science is a means of analyzing the world around us. Its aim is to describe and explain certain aspects of our universe. Made up of a set of theories, knowledge, observations and methods, it is characterized by its attempt to develop simple, intelligible models to explain our complex world. These models can then be combined with existing models to arrive at increasingly complex visions. As we construct new knowledge, these theories and models are constantly being tested, modified and reorganized.

Among other things, chemistry deals with the composition, reactions and properties of matter. It overlaps with several other scientific disciplines, such as physics, biology and materials science. It creates new substances with specific properties that it characterizes and examines. It uses a functional language to describe chemical species. The power and scope of its symbols cannot be ignored.

Chemistry is a science that deals with the composition, reactions and properties of matter. It overlaps with several other scientific disciplines.

Many impressive inventions and innovations are based on chemistry, or jointly based on chemistry and another discipline. Chemistry makes a key contribution to daily life in the fields of health, foods, the environment, new materials and energy.

Faced with the rapid emergence of large amounts of complex scientific knowledge and the proliferation of its applications,[1] people must acquire knowledge specifically related to chemistry and develop strategies that enable them to adapt to new constraints. This requires that they see the achievements of science in perspective and appreciate the impact, scope and limitations of this knowledge.

1. As presented in the Applied Science and Technology program, an "application" refers to a practical achievement, whether a technical object, a system, a product or a process.

Scientific Literacy

As an integral part of the societies it has played a major role in shaping, science represents both an important aspect of our cultural heritage and a key factor in our development. It is important to help students gradually develop their scientific literacy, to make them aware of the role that such literacy plays in their ability to make informed decisions and to give them the opportunity to discover the pleasures of science.

Curiosity, imagination, the desire to explore and the pleasure of experimentation and discovery are just as much a part of scientific activities as the need to acquire knowledge and understand, explain and create. In this regard, the field of science is not the preserve of a small group of experts. We all have a certain degree of curiosity about the phenomena around us and a fascination with scientific invention and innovation.

As an integral part of the societies it has played a major role in shaping, science represents both an important aspect of our cultural heritage and a key factor in our development.

The history of science is an integral part of this literacy and should be drawn upon. It puts scientific discoveries in perspective and enriches our understanding of them. Museums, research centres, engineering firms, health care facilities, local factories, businesses and other community organizations provide a wealth of resources for the development of scientific literacy.

The Program

The Chemistry program is an extension of the programs in Secondary Cycles One and Two. It is intended to consolidate and enrich students' scientific training and is a prerequisite for several preuniversity or technical programs at the college level. Its content focuses on one subject with compulsory concepts organized around four general concepts: gases, energy changes in reactions, reaction rate and chemical equilibrium. The content is addressed in meaningful contexts[2] that may require the application of knowledge related to the major areas of study in previous science and technology programs or knowledge associated with various subjects, themes and problems. In particular, special attention must be paid to strengthening the link between chemistry and mathematics.

The Chemistry program is designed to develop the following three competencies:

– Seeks answers or solutions to problems involving chemistry

– Makes the most of his/her knowledge of chemistry

– Communicates ideas relating to questions involving chemistry, using the languages associated with science and technology

These competencies are closely linked and related to three complementary aspects of science: the practical and methodological aspects; the theoretical, sociohistorical and environmental aspects; and the aspects relating to communication. The competencies must be developed to a high level, in particular because of the complexity of the compulsory concepts involved.

The first competency focuses on the methodology used in the sciences to solve problems. Students must become familiar with concepts and strategies using the experimental method, among other things. The students must ask questions, solve problems and find solutions through observation, modelling, measurements and experiments.

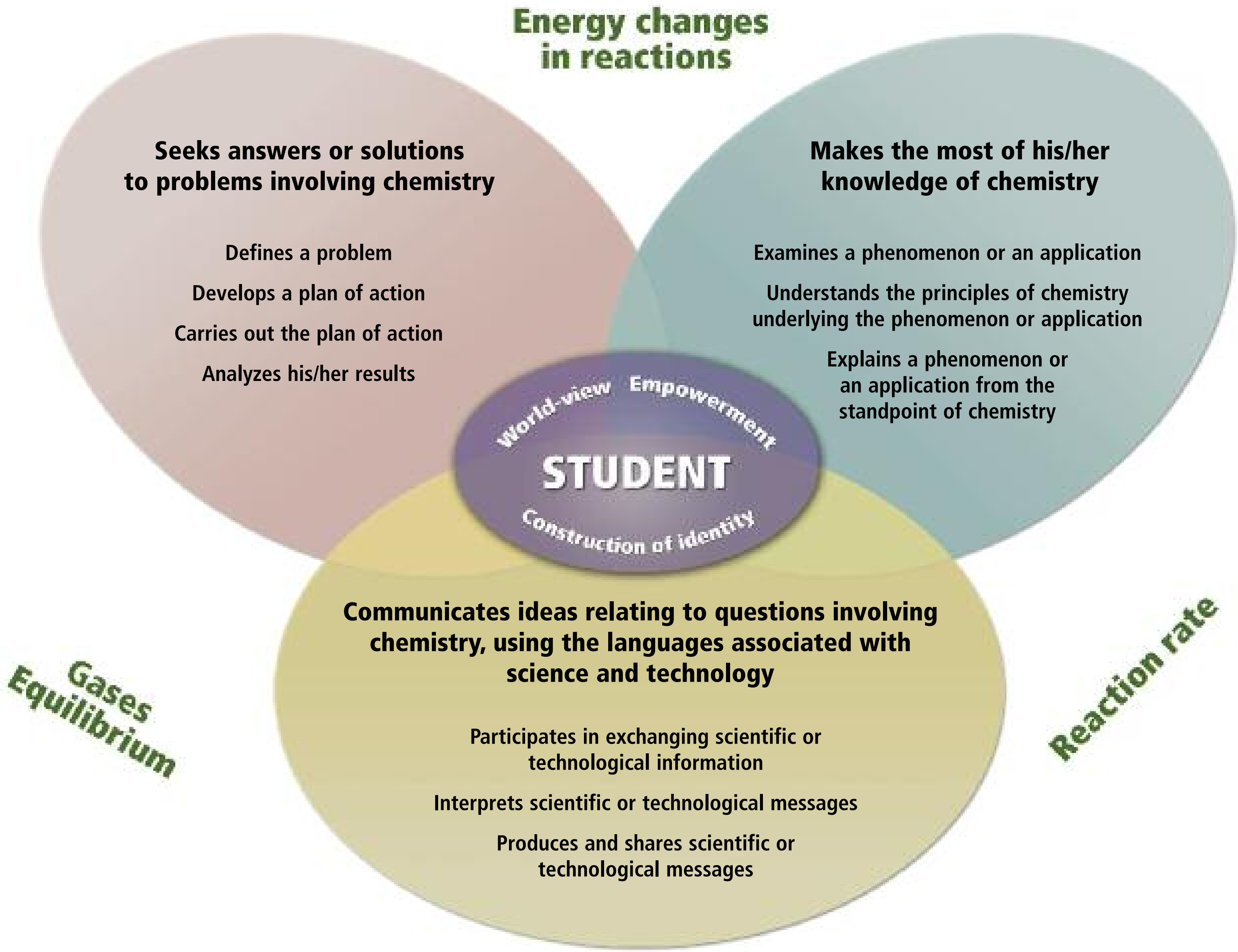
The second competency focuses on the analysis of phenomena and applications. The students must examine phenomena and applications and learn the concepts of chemistry that allow them to be understood and explained.

The third competency involves the different types of languages used in chemistry, which are essential for sharing information as well as interpreting and producing scientific and technological messages. The students are asked to participate actively in exchanges, using the languages of science and technology in accordance with established rules and conventions.

These competencies are developed together and not in isolation or sequentially. In order to master scientific methods, students need to know and be able to use the related concepts and languages. They become familiar with these methods in different contexts that give them meaning and importance.

2. With regard to each major area of study (i.e. The Material World, The Living World, etc.), Appendix A lists some of the concepts studied previously, as well as possibilities for contextualization.

CONTRIBUTION OF THE CHEMISTRY PROGRAM TO THE STUDENT'S EDUCATION



In a variety of ways, the Chemistry program is related to the other dimensions of the Québec Education Program (i.e. the broad areas of learning, the cross-curricular competencies, the Mathematics program and the other subject areas, as well as the Integrative Project).

Connections With the Broad Areas of Learning

Because of the ways in which science affects human health and well-being, the environment and the economy, there is significant overlap between the various contexts associated with the broad areas of learning and the issues and challenges raised by discoveries and inventions.

Health and Well-Being

The knowledge that students acquire in studying chemistry can provide answers to many questions related to how the body works as well as health, safety and comfort. The theoretical foundations of inorganic chemistry can be used to create representations of some of the changes that affect matter. An understanding of the chemical reactions that some environmental elements may bring about in the human body may lead students to adopt a healthier lifestyle and more balanced diet to better meet their body's needs. When necessary, this knowledge can also be used to adapt various products and molecules (e.g. skin cleaners, hair products and some treatments) to the specific biochemical profile of individuals.

The broad areas of learning are related to major issues of today. In its specific way of dealing with reality, each subject sheds a different light on these issues, helping students develop a broader world-view.

Environmental Awareness and Consumer Rights and Responsibilities

Scientific and technological knowledge helps young people increase their awareness of specific issues pertaining to their environment, such as the use of natural resources, human impact on the environment and waste management. Much advancement in science has led to consumer habits that have various consequences for the environment. Greater awareness of these environmental effects can lead to a change in behaviour. The use of an acetic acid (white vinegar) solution to clean windows is one example of a responsible use of resources.

Media Literacy

Whether it be to learn, to obtain information or to communicate, students use the various media. It is important that they learn to take a more critical view of the information they find. They must become proficient in using media-related materials and communication codes and come to understand the growing impact the media have in society and in their own everyday lives. Movies, newspapers, television and various electronic media address scientific and technological topics that can be linked to the students' everyday lives in many different ways. A strong grounding in science is often useful for assessing information. These resources must be used to advantage by teachers, who can also capitalize on students' interest in various means of communication to place their learning in context and thereby increase their motivation.

Career Planning and Entrepreneurship

The variety of activities that students are asked to carry out in the Chemistry program can help them better understand the work of people employed in this field and apply it to their personal planning.

The program competencies, along with several of the underlying concepts, strategies, techniques, attitudes and methods, will be useful in many employment sectors including nursing, engineering and criminology. Teachers can help their students become aware of these sectors, and gauge their interest in and aptitude for the related professions. This awareness is especially important at the end of secondary school, when students must define their future academic and career paths.

Citizenship and Community Life

The scientific and cultural literacy that students gradually acquire gives them a new perspective on certain social issues, which may improve the quality of their participation in the classroom, the school or society in general. Various activities, such as those that involve learning how to handle gases safely, are examples of situations that can help students learn about responsible citizenship.

Connections With the Cross-Curricular Competencies

The subject-specific competencies offer a solid basis for the development of the cross-curricular competencies, which, in turn, help broaden the scope of application of the subject-specific competencies.

Cross-curricular competencies are not developed at a theoretical level; they are rooted in specific learning contexts, usually subject-related.

Intellectual Competencies

Intellectual cross-curricular competencies play a crucial role in chemistry. The search for answers to scientific questions requires that students use information judiciously and question the reliability of their sources. It also helps them acquire new problem-solving skills and adapt them to specific situations. Developing and implementing a plan of action to solve a problem, or explaining a phenomenon or application are all ways of using creativity.

Today's society is characterized by the emergence of pseudosciences. Students must therefore learn to exercise critical judgment, especially when analyzing certain advertisements, certain scientific opinions or certain consequences of science and technology. They must try to keep media influences, social pressures and conventional wisdom in perspective in order to determine what has been validated by the scientific and technological community and what is being reported by other groups.

Methodological Competencies

The precision associated with the methods used in this program requires that students adopt effective work methods and comply with related standards and conventions.

The rapid development of information and communications technologies has played a significant role in recent advances in the world of science and technology. Using various technological tools (e.g. data-acquisition interfaces with sensors, computer-aided drafting, simulation software) in conducting experiments and solving scientific problems helps students learn to use information and communications technologies.

Personal and Social Competencies

When they take hypotheses or solutions into consideration, when they move from the abstract to the concrete or from decision to action, students are open to the range of human possibilities. They can see a greater variety of options and agree to take risks. With time, they learn to trust themselves and to learn from their mistakes, which allows them to explore new ways of achieving their potential.

To develop their knowledge of science, students must cooperate with others, since the sharing of ideas or points of view; peer or expert validation; and various collaborative research, experimental or problem-solving activities are part and parcel of the learning process.

Communication-Related Competency

Learning concepts and scientific and technological languages enable students to develop their ability to communicate appropriately. They must gradually discover the codes and conventions of these languages, become familiar with their uses and master them.

Students can further use and develop this cross-curricular competency when they join a virtual scientific community, for example by taking part in a discussion group or video conference to share information, communicate with experts on-line, present the results of their work or compare them with those of other students.

Connections With the Other Subject Areas

To ensure that students receive an integrated education, it is important to connect learning in chemistry to learning in other subjects. Any subject is defined, at least in part, by the way in which it perceives reality and by its particular view of the world. Other subjects can shed additional light on chemistry just as chemistry can help us gain a better understanding of other subjects.

Mathematics, Science and Technology

The field of mathematics is closely related to the science and technology programs. It provides a body of knowledge useful for the study of science. For example, when students follow a scientific method in Secondary V, they do not just measure, count, calculate averages, apply geometric concepts, visualize space and choose different types of representation, but also construct formal arguments or proofs. Mathematics is often of great use in developing or constructing models to explain the relationships between certain key variables. It is also used to solve both theoretical and experimental problems. Its rigorous vocabulary, graphs, notation and symbols also make mathematical language a tremendous asset to science.

Reality can rarely be explained by concepts related to a single subject. Its multiple facets can only be understood by combining the different fields of knowledge.

Mathematics also requires the development of competencies focusing on reasoning, problem solving and communication, which are related to the competencies in the Chemistry program. Their combined use fosters the transfer of learning and is especially useful in developing a capacity for abstract thought and problem-solving strategies. Chemistry also helps students understand certain mathematical concepts, such as variables, proportional relationships and various functions.

Languages

Language subjects provide students with tools essential to the development of the competencies targeted by the Chemistry program. Whether the students are reading, writing or communicating verbally, the competencies they develop in English Language Arts are indispensable for interpreting information correctly, describing or explaining a phenomenon, or justifying a methodological decision. Moreover, the different terms used in science, which are often specific to the field, help enrich the students' vocabulary. It should also be pointed out that the ability to analyze and produce oral or written texts is closely related to the competency *Communicates ideas relating to questions involving chemistry, using the languages associated with science and technology*.

A certain level of competency in French is useful for participating in a virtual community or in national or international activities such as science fairs.

Social Sciences

The study of scientific and technological developments can shed new light on contemporary issues, which are part of a historical context defined by specific social realities that sometimes require a knowledge of chemistry. Conversely, an understanding of these issues makes it possible to contextualize developments in chemistry and current research. For example, economic, political and environmental pressures all influence the development of new fuels.

Arts Education

Chemistry benefits from the creativity promoted by arts education. Some of the methods used in this program are related to the creative dynamic shared by the four Arts Education programs. This is the case, for example, with problem solving, which requires creativity.

In turn, chemistry contributes to a better understanding of the arts. For example, improvements in the use of materials in the visual arts are based on a better grasp of their characteristics.

Personal Development

In some cases, knowledge developed in chemistry class can be used to analyze questions raised in the Ethics and Religious Culture program. For example, an understanding of how certain substances react with each other can be used to support a position concerning their possible use.

Connections can also be made with Physical Education and Health. Knowledge developed through the chemistry program leads to a better understanding of the effects of certain molecules on the human body and athletic performance. Some physical activities, such as deep-sea diving, make learning content relating to the properties of gases more meaningful.

Integrative Project

All Secondary V students must now complete a personal project that meaningfully combines various aspects of what they have learned at school. A chemistry project which could, for example, be presented at a science fair, offers an opportunity for students to look in more depth at a topic that has attracted their interest during chemistry classes.

The Chemistry program can therefore easily be adapted to interdisciplinary activities. An integrated application of the different areas of learning in the Québec Education Program is recommended for a well-rounded education that gives students the tools they will need to deal with the realities of the 21st century.

Pedagogical Context

This section presents the pedagogical context that will help students develop the competencies and construct the scientific knowledge prescribed in the program. It first describes the role of the teacher, and then the role of the students.

Role of the Teacher

Teachers play a fundamental role in helping their students develop competencies. The support they provide must relate to the three aspects of every competency: the mobilization of resources in a specific context, the availability of resources and the ability to reflect on the process involved. Teachers must offer learning and evaluation situations that promote the development of the target competencies, support the students' learning progress and evaluate their level of competency development.[3]

Teachers must offer their students varied and meaningful learning and evaluation situations, support their learning progress and evaluate their level of competency development.

Offering learning and evaluation situations that promote competency development

Student competency development involves *situation-based pedagogy*. Through varied and meaningful learning and evaluation situations that become more complex as they advance in their education, students will be able to make connections between what they know and what they have to learn, and to develop their competencies.

Complex, varied situations[4]

Competencies are demonstrated and developed in learning and evaluation situations that possess a certain degree of complexity. A complex situation calls for the use of at least one competency in its entirety, requires students to mobilize internal and external resources and acquire new knowledge, leads to a final product, and presents students with an open-ended problem that they have not solved before. Such situations generally involve a set of varied activities, ranging from free exploration to goal-oriented tasks or problems to be solved by overcoming obstacles. Some activities may include application or consolidation exercises.

In the activities they propose, teachers must ensure that most experiments are used to validate or invalidate a hypothesis or proposal made by the students. This will allow them to make connections between their previous knowledge and what they are currently learning, and also between theory and practice. As much as possible, teachers must have students prepare their own experiments so that they can create a model that will assist them in drafting an experimental procedure. In some cases, teachers can present an experiment as a demonstration.

The active involvement of students is also indispensable in any problem-solving activity. The teacher must ensure that the students understand that the decisive step in solving a problem is its representation. The students must work on this representation throughout the problem-solving process. They should ultimately be able to construct a model of the problem, however rudimentary it may be, and adjust and supplement it until a solution emerges. In this way, the solution is closely linked to the representation.

It is important to note that learning and evaluation situations are more conducive to competency development when they are open-ended. Open-ended situations involve initial data that can lead to several different solutions. While sometimes complete, the initial data are generally implicit

3. On this topic, see the section "A Renewal of Practices" in Chapter 1 of the *Québec Education Program, Secondary Cycle Two*, 16-22.
4. Appendix B contains examples of learning and evaluation situations, which in some cases indicate links with the educational aims of the broad areas of learning and the learning targeted in other subjects. They also involve using both subject-specific and cross-curricular competencies.

and may even be incomplete or superfluous. The students must therefore carry out research that can generate new learning.

Whatever the activity, reflection is a required step, in particular for problem-solving activities based on complex situations. Special attention must be paid to note taking, which can help students facing a challenge, since they record the steps in their reflection and their progress toward a solution, using partial results as data. Notes form an indispensable record of the problem-solving process, and can also be used to evaluate competency development.

Meaningful situations

Learning and evaluation situations must have meaning for students by attracting their interest and posing a suitable challenge, while demonstrating the usefulness of the knowledge involved.

In this program, contextualization helps students construct chemistry concepts, while giving them the opportunity to make connections with their previous studies.

The context for the situation may be linked to broad areas of learning, cultural references, the students' everyday lives, current events, or conceptual objects and materials associated with science and technology. A context of this kind is likely to reactivate existing knowledge (scientific, technological or mathematical knowledge and prior experience). In this program, contextualization helps students construct chemistry concepts, while giving them the opportunity to make connections with their previous studies.

The activities making up the situation, whether repetitive strategies, exercises, specific tasks, experiments or problem solving, must reflect the teacher's pedagogical intention and the students' level of competency development. They must be part of a context that makes the learning meaningful. It is up to the teacher to ensure that the students always keep the context in mind, without overwhelming them with too much information.

Resources that can be used

In chemistry, as in all other subjects, the exercise of competencies is based on the mobilization of several kinds of internal and external resources: personal, informational, material, institutional and human. Personal resources consist of knowledge, skills, strategies, attitudes, techniques and methods. Some elements of the mathematics program content are among the conceptual tools needed to construct knowledge about chemistry. Their use helps students develop the capacity for abstract thought needed to design or analyze the formal models used by scientists.

Informational resources include textbooks, other documents and any other relevant source used to locate information. Material resources include instruments, tools and machines, as well as everyday objects. Institutional resources include public and parapublic organizations such as museums, research centres, engineering firms, health care facilities, local factories and businesses, and any other community organization. Students can use all these resources to broaden their scientific literacy.

Chemistry teachers and laboratory technicians are the most accessible human resources for students. Although their tasks are different, they make an essential contribution, especially in terms of safety. Input can also come from teachers of other subjects, members of the school staff, parents and experts in a particular field who are willing to contribute to the school learning process.

Supporting learning progress

Another aspect of the teacher's role is to support students as they develop competencies and, in the process, acquire knowledge. To do this, the teacher must guide them so that they can achieve the competency or master the method that, in his or her opinion, requires more attention (e.g. building a model, providing an initial explanation, using the concept of "variable," applying the concept of "measurement," representing results). The teacher may also decide to have students exercise the three competencies in an interrelated way, while focusing on one in particular.

It is important for the teacher to adapt the task to the competency level of the students, provide explanations as needed, answer their questions, suggest possible solutions, provide more supervision for the less independent students, and ensure compliance with laboratory and workshop safety rules. The teacher must also interact with the students and ensure that they interact with one another. To that end, he or she can ask them to provide explanations or examples, or trigger questions on their part by proposing counterexamples to stimulate discussion. Various pedagogical strategies, such as the problem-solving approach, case studies, academic controversy and projects, can help the students adopt a reflective approach, provided these strategies force them to ask questions and gain perspective on the process.

The teacher must provide flexible supervision, ensuring that the students are not overwhelmed by the quantity of information to be processed and helping them select relevant data to complete a task or solve a problem, as well as search for new data. The teacher must also insist on rigour, and monitor and validate the students' work. Interventions by the teacher must not devalue the students' own work, but focus on explaining mistakes and ensuring that all students learn from the mistakes identified.

The teacher is also an important resource for the students, particularly with respect to the regulation of learning and strategies involving the entire class. Carrying out these specific roles gives the teacher an ideal opportunity to refocus conceptual learning and point out connections between the students' new and prior learning. He or she also plays an active part in reviewing and synthesizing learning with the whole class.

Evaluating the level of competency development

Evaluating the level of competency development is another important aspect of the teacher's work. According to the Policy on the Evaluation of Learning, evaluation has a dual function: to support learning and to recognize competencies.

Supporting learning

It is important for teachers to observe their students regularly to help them readjust their approach and mobilize their resources more effectively. For this purpose, they must propose a wide range of learning and evaluation situations, and present observation, evaluation and recording tools for each situation. When designing these situations and tools, teachers must base them on the evaluation criteria for the competency or competencies concerned so as to be able to formulate indicators reflecting observable behaviours that make it possible to evaluate the level of competency development. Teachers should also refer to the end-of-program outcomes and the scales of competency levels.

All actions taken by the teacher must be designed to help students become aware of their difficulties and solve them or to consolidate their learning. The teacher can observe the students as they work and intervene immediately as needed. The teacher can also record observations, which can then be used to sum up the strengths and weaknesses of each student, to review with the students the strategies used and learning acquired, and to adjust his or her teaching as required.

Lastly, since evaluation as a way to support learning is also a responsibility of each student, the teacher can promote self-evaluation, coevaluation and peer evaluation, and supply tools for this purpose.

Recognizing competencies

To certify each student's level of competency development, the teacher must have a sufficient amount of relevant information to be able to form a judgment. To ensure that the judgment is valid, the teacher must refer to the evaluation criteria and end-of-program outcomes for each of the three competencies, and use the scales of competency levels developed for this program.

Role of the Student

Although the teacher sets the pedagogical framework, it is important for the students to be fully engaged in the learning process. Only they can make the necessary connections between their previous knowledge and the new concepts they must assimilate, and they must also adapt their knowledge to the concepts to be learned, and vice versa.

Only the students can make the necessary connections between their previous knowledge and the new concepts they must assimilate.

Using situations that interest the students and place the main focus on independent activity, the teacher encourages the students to take action, reason, discuss and apply their critical judgment. This requires them to take initiative, show creativity, work independently and demonstrate intellectual rigour. To do this, they must construct and use many different internal resources (knowledge and techniques, skills, methods, strategies and attitudes). If necessary, they look for a variety of information, select material resources that can help them in their learning or consult with human resources in their immediate environment. In some cases, they should look outside their family and school environment. The local community, businesses, experts and museums can all open their eyes to the outside world and give them the opportunity to consider different points of view.

It is important for students to use appropriate techniques when handling equipment and substances. If they use verification or control instruments, they must take into account possible errors in their measurements, whether caused by the instrument, the user or the environment. They must record their measurements using an appropriate number of significant figures and analyze their results based on a certain margin of error. At all times, they must comply with safety standards and handle equipment and substances with care. When in doubt, they must ask the teacher or laboratory technician to ensure that they are working safely and using the equipment and substances correctly.

Focus of the Competency

Like other science subjects, chemistry is characterized by a rigorous approach to problem solving. The problems always involve initial information, a goal to be reached and specifications describing the nature, meaning and scope of the problem. Seeking answers or solutions to chemistry problems involves using different types of reasoning and methodological procedures associated with chemistry, which make use of strategies for exploring or analyzing and require creativity, a methodological approach and perseverance. Learning how to use these methods appropriately helps students gain a better understanding of the nature of scientific activity. This competency is therefore based on the assumption that students must be offered learning and evaluation situations that go beyond the application of known formulas.

The basic and optional science and technology programs for the first two years of Secondary Cycle Two focus on scientific or technological methods. The students gradually learn to apply several methods at once in looking for an answer or a solution to a given problem. Compared with previous years, more emphasis is placed on the quantitative aspects of problems and on mathematical formalism, in addition to qualitative considerations.

Finding answers or solutions to chemistry problems involves a process that is dynamic and nonlinear.

In Secondary V, science is a key focus and only scientific methods are taught. Formal logic and mathematics become increasingly important. The problems are seldom simple and raise a number of questions that can be grouped into subproblems, each referring to scientific principles and methods.

The first step in solving a problem is to determine a way of representing it based on meaningful indicators and relevant elements. At first, this representation can be rough and may require a number of adjustments throughout the process. New learning, the use of prior knowledge and information that has not yet been taken into account, discussions with peers or the teacher, unexpected experimental results as well as the reorganization of information and knowledge often lead to more refined reformulations that come closer to achieving the goal in question. The initial representation of a problem may therefore be modified over the course of the process. Sometimes, however, the initial representation needs little or no modification, if it is based on a solid foundation of knowledge. The representation of the problem is used to explore various problem-solving scenarios in order to select the best option. This is followed by planning that takes into account material limitations and constraints and the availability of resources.

The students then follow the steps in the plan of action, taking care to record all observations that might prove useful. The correct margin of error is taken into account for all measurements. New data can require a reformulation of the representation, adaptation of the plan of action or a search for a more appropriate solution.

Analysis involves the organization, classification, prioritization, comparison and interpretation of results obtained during the problem-solving process. It consists in identifying patterns and the significant relationships that characterize them, relationships among the results themselves, and relationships between the results and the initial data or between the results and the scientific concepts. This comparison makes it possible to formalize the problem and to validate or invalidate hypotheses and draw conclusions.

When analyzing the results, it is important to take uncertainty[5] in measurements into account. By interpreting the error involved,[6] students can assess the accuracy of their result. If necessary, they can attempt to identify the probable sources of error.

In order to ensure better use of methods and strategies, students should systematically review what they have done throughout the problem-solving process. This metacognitive task should also apply to the conceptual and technical resources used and their adaptation to the requirements of the different contexts. However systematic it may be, this problem-solving process entails research and may involve trial and error. To apply it, the students must be aware of their actions and capable of reflecting on them, and ask questions for the purpose of validating the work in progress so that necessary adjustments can be made in accordance with the stated goals or the selected options. Since their results may raise new problems, achievements are always considered temporary and are a part of a continuous process of acquiring and expanding their knowledge.

Finding answers or solutions to chemistry problems involves a process that is dynamic and nonlinear. This makes it necessary to move from one phase of the problem-solving process to another and to apply the appropriate methods, strategies, techniques, principles and concepts. If these resources are to be used in combination, they must be adapted to the situation and its context.

This competency is inextricably linked to the other two and cannot be developed independently. The acquisition and use of specific knowledge is part and parcel of the process of finding solutions to chemistry problems. The laws, principles and concepts of chemistry are used to define a problem and formulate it in terms that approach an answer or solution. This competency cannot be developed without the mastery of communication strategies, since to solve chemistry problems the students must exchange information, and interpret, produce and share messages. The peer validation process is essential, as is the understanding and use of the language shared by members of the scientific community.

5. Uncertainty (absolute or relative) is the region on both sides of a measured value of a physical quantity where the true value is expected.
6. Error is the difference between the observed values and the generally accepted value.

Key Features of Competency 1

Seeks answers or solutions to problems involving chemistry

Defines a problem
Considers the context of the situation • Represents the problem • Identifies the initial data • Determines the elements that seem relevant and the relationships between them • Reformulates the problem in terms of chemistry concepts • Formulates questions, explanations or hypotheses

Develops a plan of action
Explores some of the initial explanations or solutions • Chooses an explanation or solution • Identifies the necessary resources • Plans the steps involved in its implementation

Carries out the plan of action
Follows the steps in his/her plan • Uses the appropriate resources • Carries out the required tests and tasks • Gathers potentially useful data or observations • If necessary, adjusts the plan of action or its implementation • Carries the plan of action through

Analyzes his/her results
Looks for significant patterns or relationships, if applicable • Makes connections between his/her results and chemistry concepts • Judges the appropriateness of the answer or solution found • Reviews the approach used • Suggests improvements if necessary • Draws conclusions

Evaluation Criteria

- Appropriate representation of the problem
- Development of a suitable plan of action
- Appropriate implementation of the plan of action
- Development of relevant conclusions, explanations or solutions

To evaluate the development of this competency, teachers must record a sufficient amount of relevant information about the student's work and use it to make a judgment by referring to the scales of competency levels for science and technology established by the Ministère de l'Éducation, du Loisir et du Sport (MELS).

End-of-Program Outcomes

By the end of this program, students are able to apply a process for solving practical problems involving chemistry. They attempt to understand the problem to be solved using the initial data provided for the situation and make connections among the given items of data. They define the goal to be achieved as well as the conditions involved in solving the problem. They reformulate the problem using chemistry concepts. They formulate questions, explanations or realistic hypotheses that they can justify.

The students propose a way to solve the problem. They develop their plan of action by selecting methods in order to achieve their goal. They carefully control important variables and select the relevant conceptual tools, equipment and materials.

They apply their plan of action in a safe manner and make any necessary adjustments. They collect data by correctly using the selected materials and equipment. They take the precision of the tools and equipment into account.

They analyze the data collected and formulate relevant conclusions or explanations. When presenting their results, they ensure that they use significant figures correctly, taking possible uncertainty into account. If necessary, they consider the accuracy of the result based on the discrepancy observed between their result and a generally accepted value.

If necessary, they propose new hypotheses, improvements to their solution, or new solutions. They are able to explain the steps in their approach and the way in which resources are used. If necessary, they use information and communications technologies.

Throughout the problem-solving process, the students demonstrate rigour and use appropriate qualitative explanations and mathematical formalism to support their reasoning.

Competency 2 Makes the most of his/her knowledge of chemistry

Focus of the Competency

In Cycle One, students learned to apply their scientific and technological knowledge by attempting to identify the consequences of science and technology and to understand natural phenomena and the inner workings of certain technical objects. In the first two years of Cycle Two, they apply what they have learned to the study of certain issues (in the Science and Technology, Environmental Science and Technology, and Science and the Environment programs) or technological applications (in the Applied Science and Technology program). In Secondary V, scientific knowledge is applied to an analysis of phenomena or applications.

In this program, the students are asked to examine, understand and explain phenomena or applications by applying the concepts of chemistry. It is important to specify that, in the case of an application, they do not examine technological aspects or concepts, but rather the scientific principles on which it operates. A brief technological analysis may be relevant, however, provided it highlights and clarifies the scientific principles of the application.

This competency requires the students to examine, understand and explain phenomena or applications by applying the concepts of chemistry.

To develop this competency, students must first put the phenomenon or application in context by taking into account its key aspects (e.g. social, historical, environmental, economic, political, ethical or technological). This will give students the opportunity to reactivate previously acquired scientific or technological concepts. To construct an initial representation of the phenomenon or application they are examining, they must look for useful information and determine the elements that seem most relevant as well as the connections that can be made among them.

From the standpoint of chemistry, understanding a phenomenon or application involves recognizing the principles of chemistry on which it is based. This means formulating a qualitative and often quantitative description of the principles at play, which will usually lead to the exploration and development of various underlying concepts, laws and models. This work should not be limited to the mastery of mathematical formalism or the execution of a fixed recipe, since it is important for the students to first identify and then master the fundamental concepts needed to understand the principles used to explain phenomena and applications from a scientific point of view. The empirical and observation methods, analysis, and modelling are other resources that can be used to understand the principles of chemistry. Since the same principle may be involved in several different phenomena or applications, the students may be required in some situations to adapt their explanation to a new context.

In order to make better use of the methods and strategies involved, students should systematically review what they have done throughout the process of explaining the phenomenon or application examined. This metacognitive task should also apply to the conceptual and technical resources used and their adaptation to the requirements of the different contexts.

This competency encompasses the communication skills needed to produce, interpret and share scientific messages and to use scientific and technological languages.

Key Features of Competency 2

Examines a phenomenon or an application

Considers the elements of the context • Identifies the initial data • Determines the elements that seem relevant and the relationships between them • Creates a representation of the phenomenon or application

Understands the principles of chemistry underlying the phenomenon or application

Recognizes the principles of chemistry • Describes them qualitatively or quantitatively • Makes connections between the principles using concepts, laws or models

Makes the most of his/her knowledge of chemistry

Explains a phenomenon or application from the standpoint of chemistry

Associates the principles described with the phenomenon or application • Develops an explanation • Questions the method used • Adapts the proposed explanation to other contexts, if necessary

Evaluation Criteria

– Formulation of appropriate questions
– Appropriate use of the concepts, laws and models of chemistry
– Relevant explanations
– Suitable justification of explanations

To evaluate the development of this competency, teachers must record a sufficient amount of relevant information about the student's work and use it to make a judgment by referring to the scales of competency levels for science and technology established by MELS.

End-of-Program Outcomes

By the end of this program, students can examine common applications or phenomena in context. They are able to understand and explain them using the principles of chemistry as well as appropriate methods, techniques and strategies.

When students analyze a situation from the standpoint of chemistry, they identify the phenomenon and its scientific components, constructing an initial representation that takes the relevant initial data into account.

They provide a preliminary explanation that they then develop using scientific concepts, laws and models. In the case of an application, they can handle it and take it apart as needed to understand the main subsets and the interactions of its components so that they can then associate its operation with the underlying scientific concepts or principles.

The students offer a scientific explanation for a phenomenon or an application. They justify it, using mathematical formalism among other things. When presenting their results, they ensure that they use significant figures correctly, taking possible uncertainty into account. They are able to explain their approach and the way in which resources are used. They are also able to apply their explanation to other phenomena or applications involving the same principles of chemistry.

Competency 3 Communicates ideas relating to questions involving chemistry, using the languages associated with science and technology

Focus of the Competency

Communication plays an essential role in the construction of scientific and technological knowledge. To the extent that such knowledge is developed and instituted socially, a set of common representations is required so that people can exchange ideas and negotiate points of view. This calls for a standardized language, i.e. a code that defines linguistic and graphical signs in accordance with the way they are used in the scientific and technological community. The dissemination of knowledge is also governed by certain rules. For example, research results must be validated by means of a peer review process before they are made public. Information can be communicated in different ways depending on whether it is meant for an audience of experts or nonexperts.

In this program, students are asked to use appropriate language to communicate ideas related to questions involving chemistry. They must know how to use the standards and conventions of science and technology in order to participate in exchanges on scientific or technological issues, or to interpret or produce scientific or technological information. They must also learn to respect the intellectual property rights of the people whose ideas and results they borrow. Although interpretation is particularly important, participation in exchanges and the production of messages also play an important role.

This competency is developed in situations in which students participate in exchanges of information, and in the interpretation and production of scientific or technological messages.

This competency is developed in situations in which students participate in the exchange of scientific or technological information, whether they are sharing the results of their work with peers, consulting experts to find answers to certain questions, or participating in activities such as analyzing or designing objects, systems or products, presenting a project or drafting a scientific information sheet. Particularly useful in learning to refine their representations or validate a point of view by comparing it with others, these situations must also help students develop an open-minded and receptive attitude toward the diversity of knowledge, points of view and approaches. The fact that the everyday meaning of a term is sometimes different from its meaning in scientific or technological language deserves special attention. Similarly, the meaning of concepts can differ depending on the subject area in which they are used. It is therefore essential to take into account the context of the communication situation in order to determine the issues under debate and to adapt one's discourse accordingly.

Interpretation, another important feature of the competency, is involved in reading scientific or technical articles, listening to oral presentations, understanding lab reports and using specifications, technical manuals and plans. All of these activities require that the students understand the precise meaning of words, definitions, statements, graphs, diagrams and detail drawings. They must also make explicit connections between concepts and their various graphic or symbolic representations. When consulting documents or listening to presentations, students must verify the reliability of these sources and select the information that seems appropriate to them.

In chemistry, producing scientific or technological messages is also an important aspect of this competency, since the situations may require that students develop a research procedure, write a lab report, prepare a technical manual, summarize an article, make a detail drawing of a part or give a presentation. The target audience must be taken into account in order to determine the context of the message, that is, the appropriate level of complexity, structure and means of presentation. The proper use of concepts, formalisms, symbols, graphs, diagrams and drawings also adds to the clarity, coherence and precision of the message. Information and communications technologies can be exceptionally useful and enriching in this type of communication.

In order to better combine production and interpretation strategies, students should review what they have done throughout their participation in the exchange. This metacognitive task should also apply to the conceptual and technical resources associated with communication, and their use and adaptation to the requirements of the different contexts.

This competency cannot be developed in isolation from the other two competencies in the program, as it contributes to their development. The first competency, which focuses on problem solving as it relates to chemistry, involves following certain standards and conventions, whether in developing a research procedure or production scenario, or in explaining laws and principles or presenting the results of an experiment. Tables, symbols, graphs, diagrams, detail and general drawings, scale models, mathematical equations and models can all be used to present information, but it is important to use them in accordance with the rules specific to the fields of science, technology and mathematics.

The scientific concepts related to chemistry, which are the focus of the second competency, cannot be learned or used in isolation from a language and a certain type of discourse. For example, scientific laws are a way of modelling phenomena and are usually expressed through definitions or mathematical formalism. Understanding these laws means being able to associate them with the phenomena they represent or the applications that give them concrete expression.

Key Features of Competency 3

Participates in exchanging scientific or technological information

Is open to other points of view • Validates his/her point of view, explanation or solution by comparing it with others • Integrates appropriate scientific and technological terms into his/her oral and written vocabulary

Interprets scientific or technological messages

Makes sure the sources are reliable • Identifies relevant information • Understands the precise meaning of words, definitions and statements • Makes connections between concepts and their various graphic or symbolic representations • Selects the significant elements

Communicates ideas relating to questions involving chemistry, using the languages associated with science and technology

Produces and shares scientific or technological messages

Takes the target audience and context into account • Structures his/her message • Uses the appropriate types of language in accordance with established standards and conventions • Uses the appropriate forms of presentation • Demonstrates rigour and coherence

Evaluation Criteria

– Accurate interpretation of scientific or technological messages
– Appropriate production or sharing of scientific or technological messages
– Use of appropriate scientific and technological terminology, rules and conventions

To evaluate the development of this competency, teachers must record a sufficient amount of relevant information about the student's work and use it to make a judgment by referring to the scales of competency levels for science and technology established by MELS.

End-of-Program Outcomes

By the end of this program, students can interpret and produce chemistry-related scientific or technological messages in oral, written or visual form.

When interpreting messages, they use the languages associated with chemistry. They correctly use scientific, technological, mathematical, symbolic and everyday language depending on the situation. They take the reliability of their sources into account.

If necessary, they define the words, concepts and expressions used by referring to reliable sources. They review all the information consulted and then identify and use the elements they deem relevant and necessary for an accurate interpretation of the message.

They produce clear, well-structured and well-worded messages. They follow conventions, while using the appropriate means of presentation. They select and use necessary tools, such as information and communications technologies, which help them deliver their message effectively. At all times, they adapt their messages to their target audience. Using everyday language, they are able to explain the messages they have produced or interpreted.

When necessary, the students compare their ideas with those of others. They defend their ideas, but adjust them when other people's arguments can help fine-tune their thinking. They always respect intellectual property rights in producing their messages.

Program Content: Constructing and Using Resources

Like the other Science and Technology programs, the Chemistry program is aimed at consolidating and enriching students' scientific and technological literacy. It is also designed to educate students about the impact of science on individuals, society and the environment, and to prepare some students for a scientific or technological career.

The resources to be developed in this program complement those developed in previous science and technology programs to allow students to use concepts in a more specialized way in a wider range of contexts connected with the material, living and technological worlds as well as Earth and space. The contextualization suggestions in Appendix A provide valuable opportunities for the development of the target competencies and resources.

The resources are presented in two parts. The first part addresses the compulsory concepts, and the second part focuses on the methods, strategies and attitudes that students must acquire, along with compulsory techniques. In essence, the methods correspond to the problem-solving approaches normally used in the sciences. The strategies are implemented to ensure better use of the methods. The attitudes, whether linked to knowledge or skills, help the students develop a sense of commitment to and responsibility for their work. Lastly, the techniques involve methodical procedures often used in the sciences, and play a fundamental role in competency development.

It is important to note that, in this program, the targeted level of concept and competency development requires students to use various mathematical concepts, such as first- and second-degree equations and polynomial, exponential and logarithmic functions. These concepts are covered in the mathematics programs from preceding years, or in each mathematics option in the second and third years of Secondary Cycle Two.

Compulsory Concepts[7]

The compulsory concepts are organized around general concepts related to gases, energy changes in reactions, reaction rates and chemical equilibrium. They are presented in a two-column table. The first column lists the general concepts and orientations, which develop, set and specify the conceptual foundations, while giving teachers a certain amount of latitude. Occasionally, additional notes provide information about the scope of the concepts under study. The second column lists the compulsory concepts, but teachers should in no way feel bound by this list. The learning and evaluation situations should in fact be designed to go beyond these minimum requirements.

A table of cultural references follows. These references can enrich learning and evaluation situations and contribute to the development of integrative educational activities that reflect the students' social, historical, cultural and everyday reality. Connections can often be made to the broad areas of learning and to the other subject areas.

7. Appendix C contains a synoptic table showing all compulsory concepts associated with The Material World and covered from Secondary I to V.

Orientation	Compulsory Concepts
Gases The extensive use of gases in many different areas of human activity makes it important to study the reactivity of various gaseous substances. This provides information, for example, on their possible uses and on ways of handling them safely. The similarities observed in the behaviour of various gases (compressibility, expansion, diffusion, undefined shape and volume, etc.) have led to the definition of Kinetic molecular theory. At the beginning of Cycle Two, the study of gases focused on the relationship between pressure and volume. In this program, students continue to examine this topic by looking at the general gas law and the ideal gas law. Dalton's law, also called the "law of partial pressures," is useful in the study of gaseous mixtures. The application of these laws requires mastery of the mathematical operations connected with the conversion of units of measure and multi-variable algebraic expressions. Avogadro's hypothesis explains volumetric combinations associated with chemical reactions involving gases. As a corollary of this hypothesis, molar volume is used to simplify calculations concerning the quantity of gases consumed or produced. The molar volumes used are those established at standard temperature and pressure (0°C and 101.3 kPa), and at standard ambient temperature and pressure (25°C and 101.3 kPa).	– Chemical properties of gases • Reactivity – Physical properties of gases • Kinetic theory of gases • General gas law • Ideal gas law • Dalton's law • Avogadro's hypothesis • Molar volume of a gas
Energy changes in reactions The energy balance of a reaction may be represented in an energy diagram. The construction and interpretation of an energy diagram provides a description of the enthalpy change (energy stored as kinetic and potential energy) of the substances involved and of certain aspects of chemical dynamics, such as activation energy. The additivity of reaction heats (Hess's law) or bonding enthalpies are among the methods used to evaluate the molar heat of reaction. Calorimetry is a way to experimentally determine the quantity of heat involved in certain chemical reactions or physical changes.	– Energy diagram – Activation energy – Enthalpy change – Molar heat of reaction
Reaction rate The rate at which reactants are transformed into products depends on several factors (nature of the reactants, concentration, surface area, temperature, catalysts). There are therefore many different ways to speed up or slow down changes in matter. The rate law uses algebraic expressions to compare the rates of various chemical reactions and, in some cases, to calculate their numerical value. The rate law provides a better understanding of the dynamic nature of equilibrium and can be used to express equilibrium constants mathematically.	– Factors that influence reaction rate • Nature of reactants • Concentration • Surface area • Temperature • Catalysts – Rate law

Orientation	Compulsory Concepts
Chemical equilibrium Dynamic equilibrium is a state found in many different chemical, physical and biological systems. The qualitative study of the state of equilibrium and the factors that influence it is a compulsory part of the program. Le Chatelier's principle is used among other things to predict changes in systems after their conditions have been modified. Whatever the system considered, the interpretation and calculation of the equilibrium constant expression (water ionization constant, acidity and alkalinity constants, solubility-product constant) can be used to deal with both the qualitative and quantitative aspects of chemical equilibrium. The use of first- and second-degree equations may be necessary. The water ionization constant is used to understand the interdependency of the molar concentrations of hydronium and hydroxide ions. The pH of aqueous solutions can be calculated by determining either of these molar concentrations and using logarithmic functions. Scientific notation must be mastered. **Note:** For the calculation of equilibrium constants, the systems studied should consist of simple substances, with molecular formulas of the form XY, XY_2 or X_2Y.	– Factors that influence the state of equilibrium • Concentration • Temperature • Pressure – Le Chatelier's principle – Equilibrium constant • Water ionization constant • Acidity and alkalinity constants • Solubility-product constant – Relationship between the pH and the molar concentration of hydronium and hydroxide ions

Possible Cultural References		
History	**Community resources**	**Events**
– Amedeo Avogadro – Robert Boyle – Jacques Charles – Louis Joseph Gay-Lussac – Antoine Laurent de Lavoisier – Henry Louis Le Chatelier – Edme Mariotte – Maud Leonora Menten – William Thomson	Association francophone pour le savoir (ACFAS) Chemical Institute of Canada (CIC) Conseil de développement du loisir scientifique (CDLS) International Union of Pure and Applied Chemistry (IUPAC) National Research Council Canada (NRC)	Nobel Prize for chemistry Science fairs

Methods, Strategies, Attitudes and Techniques

This section addresses the methods, strategies, attitudes and techniques recommended in the program. While they are different from the concepts, these elements are just as important in the development of competencies. They are designed to consolidate the elements covered in the first two years of Cycle Two.

Methods

Methods require special attention. They should not be applied in isolation, but in learning and evaluation situations in which several of them are combined. The ability to apply these methods in combination is an indicator of proficiency.

Five methods are presented here: modelling, observation, analysis, and the experimental and empirical methods.

Modelling

Modelling consists in constructing a representation of an abstract situation, one that is difficult to observe or impossible to see. This representation can be a text, a drawing, a mathematical formula, a chemical equation, a software program or a scale model. Over time, the model becomes more refined and complex. It may be valid only for a certain amount of time and in a specific context and, in many cases, it must be modified or rejected. It is also important to consider the context in which it was created. A model must help people understand a given reality, explain certain properties of that reality and predict new observable phenomena.

Observation method

The observation method is an active process intended to help the observer interpret facts on the basis of his or her predetermined criteria and generally accepted criteria within a given field. In light of the information collected, the students gain a new understanding of the facts, which is inextricably linked to the context in which the observations were made. In his or her interpretation and organization of information, the observer reinterprets the physical world on the basis of his or her assumptions and the conceptual schemes that are an integral part of what he or she brings to the observation process. All observations involve a theoretical model established by the observer.

Analysis

The elements that determine or make up a phenomenon, an object or a system, as well as the interactions between these elements, can be identified through analysis. Analysis also leads to the identification of structural and functional components, which can in turn be analyzed, and to the determination of their hierarchical or interdependent connections. In some cases, this method involves using a broader understanding of a system to determine the function of its parts and the relationships between them, thereby making it possible to highlight the dynamics of a complex system and examine its behaviour over time. This aspect of the analytical method is particularly useful in studying phenomena and applications.

Experimental method

The experimental method begins with the formulation of preliminary explanations. Then students can begin looking for an answer and defining the framework of the experiment. It then becomes necessary to develop an experimental procedure in order to identify a certain number of variables to be manipulated. The aim of the procedure is to identify and compare observable or quantifiable elements and check them against the initial hypotheses. Moving back and forth between the different stages of the experimental method raises new questions and allows students to formulate new hypotheses, adjust the experimental procedure and take the limitations of the experiment into account.

Empirical method

The empirical method involves field research without any manipulation of variables. Its spontaneity does not detract from the methodology involved (for example, a sample survey is an empirical approach that leaves nothing to chance). Often based on intuitive models, this method sometimes provides a way of exploring and representing the elements of a problem. Often, it can lead to a number of preliminary ideas, hypotheses and theories, as well as new techniques and possible avenues for other research projects.

Strategies

Some strategies used in science can help students develop the program's three competencies.

Exploration strategies	Analytical strategies
– Collecting as much scientific and contextual information as possible to define a problem or predict patterns – Referring to similar problems that have already been solved – Generalizing on the basis of several structurally similar cases – Anticipating the results of a method – Developing various scenarios – Exploring various possible solutions – Considering various points of view on scientific issues	– Identifying the constraints and important elements related to the problem-solving situation – Dividing a complex problem into simpler subproblems – Using different types of reasoning (e.g. inductive and deductive reasoning, comparison, classification, prioritization) in order to process information – Reasoning by analogy in order to process information and adapt his/her scientific knowledge – Selecting relevant criteria to help him/her determine where he/she stands on a scientific issue.

Attitudes

The adoption of a variety of attitudes makes it easier for students to invest in the methods used and to develop a sense of responsibility for their own actions and with respect to society in general. Attitudes are an important factor in the development of the competencies.

Intellectual attitudes	Behavioural attitudes
– Curiosity – Sense of initiative – An inclination to take intellectual risks – Interest in comparing different ideas – Receptivity to original solutions – Intellectual rigour – Objectivity – Methodical approach to their work – Concern about accurate measurements and calculations – Concern about using proper and precise language	– Discipline – Independence – Concern for effectiveness – Concern for efficiency – Perseverance – Concern for a job well done – Sense of responsibility – Willingness to work hard – Willingness to cooperate effectively with others – Concern for health and safety – Respect for life and the environment – Attentiveness – Respect for themselves and others – Team spirit – International solidarity in dealing with major issues

Techniques

Often essential, techniques involve methodical procedures that provide guidelines for the proper application of theoretical knowledge. The techniques listed below are compulsory, like the compulsory concepts.

Techniques related to laboratory work
– Safely using laboratory or workshop materials and equipment – Using observational instruments – Preparing solutions – Gathering samples
Measurement techniques
– Checking the reliability, accuracy and sensitivity of measuring instruments (calibration, adjustment) – Using measuring instruments – Interpreting measurement results (significant figures, uncertainty related to measurements, errors) **Note:** For mathematical operations involving measurements, the calculation of uncertainty is not required.

APPENDIX A – CONTEXTUALIZATION OF LEARNING

This Appendix sets out the compulsory concepts to be studied in relation to each of the general concepts covered in the Chemistry program, various possibilities for contextualization and the concepts examined in previous science and technology programs, all of which can help students assimilate the compulsory concepts for this program. Focusing on the study of phenomena and applications, the contextualization possibilities provide opportunities to synthesize learning by enabling students to apply previously acquired knowledge and skills and develop the three subject-specific competencies as well as the targeted concepts. These possibilities are suggested to support teachers in their work and provide for the integration of scientific, technological and mathematical knowledge. Other contexts can also be meaningful, and teachers should choose the contexts most likely to be of interest and benefit to their students.

Contextualization of chemistry concepts and connections with concepts examined previously

Gases				

Compulsory concepts	– Chemical properties of gases
	  • Reactivity
	– Physical properties of gases
	  • Kinetic theory of gases
	  • General gas law
	  • Ideal gas law
	  • Dalton's law
	  • Avogadro's hypothesis
	  • Molar volume of a gas			

Possibilities for contextualization	– Internal combustion engine – Hot air balloons / airships / weather balloons – Air pumps – Gas handling, use and storage – Deep-sea diving – Respiratory diseases – Medical uses of gas (e.g. anesthetics, resuscitation) – Food-related uses of gas (e.g. preservation, ripening, gasification) – Gases in the Earth's primitive atmosphere – Volcanic eruptions – Gas-using device – Ozone layer – Measuring and control instruments using gas (e.g. manometer, sphygmomanometer, barometer) – Filters and gas masks			
	The Material World	**The Living World**	**The Earth and Space**	**The Technological World**
Concepts examined previously	– States of matter – Phase changes – Pressure, volume, temperature – Particle model of matter – Atoms and molecules	– Respiratory system – Ecotoxicology (contaminants) – Food processing	– Conditions conducive to the development of life – Contamination – Permafrost – Major stages in the history of life on Earth	– Materials (degradation, protection) – Ferrous alloys – Nonferrous metals and alloys

Contextualization of chemistry concepts and connections with concepts examined previously (*cont.*)

Energy changes in reactions				
Compulsory concepts	– Energy diagram – Activation energy – Enthalpy change – Molar heat of reaction			
Possibilities for contextualization	– Refrigeration and air conditioning – Cooling and heating packs – Energy efficiency of fuels – Food choices – Regulation of heat in the geosphere – Solar energy generation (solar panels) – Fossil fuels – Petroleum products and biofuels			
	The Material World	**The Living World**	**The Earth and Space**	**The Technological World**
Concepts examined previously	– Chemical bonds – Endothermic and exothermic reactions	– Input and output – Energy value of different foods – Ecosystem dynamics – Flow of matter and energy	– Geological time scale – Natural forms of energy – Flow of energy from the sun – Renewable and non-renewable energy resources	– Biotechnologies (biodegradation of pollutants)

Contextualization of chemistry concepts and connections with concepts examined previously (*cont.*)

Reaction rate				
Compulsory concepts	– Factors that influence reaction rate • Nature of reactants • Concentration • Surface area • Temperature • Catalysts – Rate law			
Possibilities for contextualization	– Combustion rate – Fire protection methods – Catalytic converters – Catalysts and inhibitors – Food additives – Enzyme reactions – Pharmacokinetics (action, elimination of medication) – Biodegradable plastics – Fertilizer dissolution rate – Surface treatments (protection)			
	The Material World	**The Living World**	**The Earth and Space**	**The Technological World**
Concepts examined previously	– Concentration – Temperature – Pressure	– Food processing – Dynamics of communities (disturbance) – Ecological footprint	– Soil types – Stratigraphic layers	– Biotechnologies (pasteurization, biodegradation of pollutants, wastewater treatment) – Ferrous alloys – Nonferrous metals and alloys – Wood and modified wood – Plastics – Ceramics – Composites – Materials (degradation and protection)

Contextualization of chemistry concepts and connections with concepts examined previously (*cont.*)

Chemical equilibrium				
Compulsory concepts	– Factors that influence the state of equilibrium • Concentration • Temperature • Pressure – Le Chatelier's principle – Equilibrium constant • Water ionization constant • Acidity and alkalinity constants • Solubility-product constant – Relationship between the pH and the molar concentration of hydronium and hydroxide ions			
Possibilities for contextualization	– Household cleaning products – Haber process – Fishkeeping – Swimming pool maintenance products – Control of blood pH – Control of gastric acidity – Impact of human activities on biogeochemical cycles – Biocides (e.g. pesticides, insecticides) – Stratospheric ozone – Physicochemical soil decontamination			
	The Material World	**The Living World**	**The Earth and Space**	**The Technological World**
Concepts examined previously	– Electrolytic dissociation – pH scale – Acid-base neutralization – Stoichiometry	– Photosynthesis and respiration – Maintenance of blood balance – Physical and behavioural adaptation	– Contamination – Carbon cycle, nitrogen cycle, phosphorous cycle – Water cycle – Greenhouse effect	– Biotechnologies (biodegradation of pollutants, wastewater treatment) – Composites

Hydrogen Production

1. Educational aim

This activity is intended to help students develop competency 1, *Seeks answers or solutions to problems involving chemistry,* by requiring them to solve a practical problem concerning reaction rates.

2. Approximate time required

The activity requires two 75-minute periods.

3. Broad area of learning and focus of development

Environmental Awareness and Consumer Rights and Responsibilities

– Construction of a healthy environment based on sustainable development

Research into waste recovery helps improve resource management.

4. Description of the activity

Introduction

During the summer, you work for a factory specializing in magnesium processing. You observe that waste is thrown away even though it still contains some metallic magnesium. You suggest to your supervisor that this waste be processed with an acidic solution to produce hydrogen gas, which can be used as fuel. Your supervisor thinks it would be possible to bring about a reaction between this waste and acidic solutions available in the factory. He tells you that the rate of the reaction must be limited to between 1.2 and 1.5 litres of hydrogen gas production per hour. He has asked you to determine the type and concentration of acid needed to produce hydrogen gas at this rate.

5. Work expected of students

The students must produce a laboratory report that includes:

– an experimental procedure

– the results of the experiment

– at least two suggestions for acidic solutions to be used (type and concentration to be specified) and the experimental value of the reaction rate for each solution

– a justification for the suggested solutions

6. Targeted subject-specific competency

Competency 1 – *Seeks answers or solutions to problems involving chemistry*

– Defines a problem
  - Provides an initial representation of the problem (measurement of gas formation rate)
  - Identifies relevant data (effect of nature and concentration of the acidic solution on the reaction rate)
  - Formulates hypotheses (chooses acid, concentration, etc

– Develops a plan of action
  - Determines the resources required (measuring instruments [burette, stopwatch], substances, etc.)
  - Plans the steps involved in the plan of action (determines the procedure)

– Carries out the plan of action
  - Carries out the required tests and tasks (experiment setup, measurements, etc.)
  - Gathers the data

– Analyzes his/her results
  - Makes connections between his/her results and the scientific concepts (calculates reaction rate, interprets results)
  - Develops relevant conclusion based on the initial constraints (makes suggestions concerning the type of acid, the concentration range, etc.)

7. Targeted cross-curricular competencies

Solves problems; Communicates appropriately

8. Resources (specified in the program content)*

Compulsory concepts

Compulsory concepts for the current year
– Factors that influence reaction rate • Nature of reactants • Concentration – Physical properties of gases • General gas law • Ideal gas law • Molar volume of a gas
Concepts from previous years
– Concentration (mol/L) – Stoichiometry – Concept of mole

Methods

– Experimental method, analysis

Technique

– Interpreting measurement results (significant figures)

9. Evaluation criteria

Competency 1

– Appropriate representation of the problem

– Development of a suitable plan of action

– Appropriate implementation of the plan of action

– Development of relevant conclusions, explanations or solutions

* Other resources presented in the program content (e.g. strategies, attitudes, techniques) can be taken into consideration.

Fishkeeping

1. Educational aim

This activity is intended to help students develop competencies 2 and 3, *Makes the most of his/her knowledge of chemistry* and *Communicates ideas relating to questions involving chemistry, using the languages associated with science and technology* through an examination of the scientific issues involved in setting up a freshwater aquarium.

2. Approximate time required

The activities require three 75-minute periods (excluding documentary research).

3. Broad area of learning and focus of development

Environmental Awareness and Consumer Rights and Responsibilities

– Knowledge of the environment

Knowledge of the scientific concepts underlying the work involved in fishkeeping helps students make connections among the various elements of an environment.

4. Description of the activity

Introduction

You own a freshwater aquarium that is in a state of equilibrium, with a few aquatic plants and five guppies (*Poecilia reticulata*). The current aquarium parameters are given in the table below.

Parameters	Current conditions
Volume of water	40 L
Lighting	11 hours/day
Temperature	21°C
pH	6.8
Total water hardness	160 mg/L

You want to add another species of fish to your aquarium. Given their behaviour and some of the characteristics of their environment, you have narrowed your choice down to *Xiphophorus maculatus* (platy), *Poecilia velifera* (sailfin molly) and *Hemigrammus erythrozonus* (glowlight tetra). You must get more information about the new species you have selected in order to determine the ideal conditions for introducing it alongside the guppies.

Your task is to find out what changes must be made to the chemical composition of the aquarium water, and then to suggest a realistic way of making these changes.

Activities

The students must choose a species of freshwater fish that can live alongside the guppies, and find out more about its specific needs.

They must first describe the chemical characteristics of the living environment required by the two species. They must determine what needs to be done to change the existing state of equilibrium in the aquarium water to allow both species to live side by side. The information must be presented clearly in a document and highlight the relationships among the various parameters.

In addition, the students must find the ideal place to put the aquarium in the room where it is located (proximity of the heating system, windows, etc.) and justify their choice using scientific arguments.

5. Work expected of the students

The students must produce a document that includes:

– a description of the current aquarium environment and the changes proposed

– a presentation of the relationships among the external factors and their effects (temperature, pH, light, concentration), with a description of the changes to be made to the current state of equilibrium

– a proposed series of steps to be taken to adapt the chemical composition of the aqueous solution in the aquarium to the requirements of both species (addition or removal of products, location of the aquarium, etc.)

– a scientific justification for the proposed solutions

6. Targeted subject-specific competencies

Competency 2 – *Makes the most of his/her knowledge of chemistry*

– Examines a phenomenon or an application

- Identifies the initial data (does research to find the chemical composition of the water required for both species)
- Determines relevant elements and the relationships between them (identifies the parameters that must be modified)
- Represents the phenomenon (component substances, possible interactions, concentrations)

– Understands the principles of chemistry underlying the phenomenon or application

- Recognizes the principles and concepts related to chemical equilibrium (factors influencing equilibrium, equilibrium constant, Le Chatelier's principle)
- Constructs and describes the principles
- Makes connections among the concepts and examines how changes associated with these concepts influence the state of equilibrium of the aqueous solution

– Explains a phenomenon or an application from the standpoint of chemistry

- Uses Le Chatelier's principle and equilibrium constants to explain the effect of the proposed changes on the state of equilibrium required for the two species of fish to live side by side.

Competency 3 – *Communicates ideas relating to questions involving chemistry, using the languages associated with science and technology*

– Participates in exchanging scientific or technological information

- Discusses changes to be made and the work involved in producing the document

– Interprets scientific or technological messages

- Becomes familiar with information on the two species of fish

– Produces and shares scientific or technological messages

- Produces the document

7. Targeted cross-curricular competencies

Uses information; Cooperates with others; Communicates appropriately

8. Resources (specified in the program content)*

Compulsory concepts

Compulsory concepts for the current year
– Factors that influence the state of equilibrium • Concentration • Temperature – Le Chatelier's principle – Equilibrium constant • Water ionization constant – Relationship between the pH and the molar concentration of hydronium and hydroxide ions
Concepts from previous years
– Solubility – Nomenclature and notation rules – pH scale – Dynamics of communities – Disturbance

Methods

– Analysis and modelling

* Other resources presented in the program content (e.g. strategies, attitudes, techniques) can be taken into consideration.

9. Evaluation criteria

Competency 2

- Formulation of appropriate questions
- Appropriate use of the concepts, laws and models of chemistry
- Relevant explanations
- Suitable justification of explanations

Competency 3

- Accurate interpretation of scientific or technological messages
- Appropriate production or sharing of scientific or technological messages
- Use of appropriate scientific and technological terminology, rules and conventions

APPENDIX C – DISTRIBUTION OF THE COMPULSORY CONCEPTS ASSOCIATED WITH THE MATERIAL WORLD, SECONDARY CYCLES ONE AND TWO[8]

General Education Path

Cycle One	Cycle Two (compulsory program)		Cycle Two (optional program)	Cycle Two (optional program)
Secondary I and II	**Secondary III**	**Secondary IV**	**Secondary IV**	**Secondary V**
Science and Technology	**Science and Technology**		**Environmental Science and Technology**	**Chemistry**
Properties – Characteristic properties – Mass – Volume – Temperature – States of matter – Acidity/alkalinity	**Properties of matter** – Characteristic physical properties • Melting point • Boiling point • Density • Solubility – Characteristic chemical properties • Reaction to indicators – Properties of solutions • Concentration (%, g/L) • Solute • Solvent	**Physical properties of solutions** – Concentration (ppm) – Electrolytes – pH scale – Electrolytic dissociation – Ions – Electrical conductivity	**Physical properties of solutions** – Concentration (ppm, mole/L) – Strength of electrolytes	**Gases** – Chemical properties of gases • Reactivity – Physical properties of gases • Kinetic theory of gases • General gas law • Ideal gas law • Dalton's law • Avogadro's hypothesis • Molar volume of a gas

8. For the full array of compulsory concepts associated with the four major areas covered in Secondary Cycles One and Two in the General Education Path, see Appendix D of the Environmental Science and Technology program. The same information pertaining to the Applied General Education Path is found in Appendix D of the Science and the Environment program.

Cycle One	Cycle Two (compulsory program)		Cycle Two (optional program)	Cycle Two (optional program)
Secondary I and II	**Secondary III**	**Secondary IV**	**Secondary IV**	**Secondary V**
Science and Technology	**Science and Technology**		**Environmental Science and Technology**	**Chemistry**
Changes – Physical change – Chemical change – Conservation of matter – Mixtures – Solutions – Separation of mixtures	**Changes in matter** – Physical changes • Dissolution • Dilution • Phase changes – Chemical changes • Decomposition and synthesis • Oxidation • Precipitation – Forms of energy (chemical, thermal, mechanical, radiation) – Particle model	**Chemical changes** – Combustion – Photosynthesis and respiration – Acid-base neutralization reaction – Balancing chemical equations – Law of conservation of mass	**Chemical changes** – Formation of salts – Stoichiometry – Types of bonds • Covalent • Ionic – Endothermic and exothermic reactions	**Energy changes in reactions** – Energy diagram – Activation energy – Enthalpy change – Molar heat of reaction
			Nuclear transformations – Nuclear stability – Radioactivity – Fission and fusion	**Reaction rate** – Factors that influence reaction rate • Nature of reactants • Concentration • Surface area • Temperature • Catalysts – Rate law

<table>
<tr><th>Cycle One</th><th colspan="2">Cycle Two
(compulsory program)</th><th>Cycle Two
(optional program)</th><th>Cycle Two
(optional program)</th></tr>
<tr><th>Secondary I and II</th><th>Secondary III</th><th>Secondary IV</th><th>Secondary IV</th><th>Secondary V</th></tr>
<tr><th>Science and Technology</th><th colspan="2">Science and Technology</th><th>Environmental Science and Technology</th><th>Chemistry</th></tr>
<tr><td>Organization
– Atom
– Element
– Periodic table
– Molecule</td><td>Organization of matter
– Pure substance (compound, element)
– Homogeneous and heterogeneous mixtures</td><td>Organization of matter
– Rutherford-Bohr atomic model
– Lewis notation
– Groups and periods of the periodic table</td><td>Organization of matter
– Neutron
– Simplified atomic model
– Nomenclature and notation rules
– Polyatomic ions
– Concept of mole
– Avogadro’s number</td><td>Chemical equilibrium
– Factors that influence the state of equilibrium
• Concentration
• Temperature
• Pressure
– Le Chatelier’s principle
– Equilibrium constant
• Water ionization constant
• Acidity and alkalinity constants
• Solubility-product constant
– Relationship between the pH and the molar concentration of hydronium and hydroxide ions</td></tr>
<tr><td></td><td></td><td></td><td>Periodic table
– Relative atomic mass
– Atomic number
– Periodicity of properties
– Isotopes</td><td></td></tr>
</table>

Cycle One	Cycle Two (compulsory program)		Cycle Two (optional program)	Cycle Two (optional program)
Secondary I and II	**Secondary III**	**Secondary IV**	**Secondary IV**	**Secondary V**
Science and Technology	**Science and Technology**		**Environmental Science and Technology**	**Chemistry**
	Fluids – Compressible and incompressible fluids – Pressure – Relationship between pressure and volume	**Electricity and electromagnetism** Electricity – Electrical charge – Static electricity – Ohm's law – Electrical circuits – Relationship between power and electrical energy Electromagnetism – Forces of attraction and repulsion – Magnetic field of a live wire	**Electricity and electromagnetism** Electricity – Kirchhoff's laws – Electrical field – Coulomb's law Electromagnetism – Magnetic field of a solenoid	
		Transformation of energy – Law of conservation of energy – Energy efficiency – Distinction between heat and temperature	**Transformation of energy** – Specific heat capacity – Relationship among work, force and displacement – Effective force – Relationship between work and energy – Relationship among potential energy, mass, acceleration and displacement – Mass and weight – Relationship among kinetic energy, mass and velocity	

Cycle One	Cycle Two (compulsory program)		Cycle Two (optional program)	Cycle Two (optional program)
Secondary I and II	**Secondary III**	**Secondary IV**	**Secondary IV**	**Secondary V**
Science and Technology	**Science and Technology**		**Environmental Science and Technology**	**Chemistry**
	Waves – Frequency – Wavelength – Amplitude – Decibel scale – Electromagnetic spectrum – Deviation of light waves – Focal point of a lens			

Applied General Education Path

Cycle One	Cycle Two (compulsory program)		Cycle Two (optional program)	Cycle Two (optional program)
Secondary I and II	**Secondary III**	**Secondary IV**	**Secondary IV**	**Secondary V**
Science and Technology	**Applied Science and Technology**		**Science and the Environment**	**Chemistry**
Properties – Characteristic properties – Mass – Volume – Temperature – States of matter – Acidity/alkalinity	**Properties of matter** – Characteristic physical properties • Melting point • Boiling point • Density – Characteristic chemical properties • Reaction to indicators – Properties of solutions		**Physical properties of solutions** – Solubility – Concentration (g/L, ppm, %, mole/L) – Electrolytes – pH scale – Ions – Electrical conductivity	**Gases** – Chemical properties of gases • Reactivity – Physical properties of gases • Kinetic theory of gases • General gas law • Ideal gas law • Dalton’s law • Avogadro’s hypothesis • Molar volume of a gas
Changes – Physical change – Chemical change – Conservation of matter – Mixtures – Solutions – Separation of mixtures	**Changes in matter** – Physical changes – Chemical changes – Forms of energy – Particle model	**Chemical changes** – Combustion – Oxidation	**Chemical changes** – Precipitation – Decomposition and synthesis – Photosynthesis and respiration – Acid/base neutralization reaction – Salts – Balancing chemical equations – Law of conservation of mass – Stoichiometry – Types of bonds • Covalent • Ionic – Endothermic and exothermic reactions	**Energy changes in reactions** – Energy diagram – Activation energy – Enthalpy change – Molar heat of reaction

Cycle One	Cycle Two (compulsory program)		Cycle Two (optional program)	Cycle Two (optional program)
Secondary I and II	**Secondary III**	**Secondary IV**	**Secondary IV**	**Secondary V**
Science and Technology	**Applied Science and Technology**		**Science and the Environment**	**Chemistry**
			Physical changes – Dissolution – Dilution	
Organization – Atom – Element – Periodic table – Molecule	**Organization of matter** – Pure substance (compound, element) – Homogeneous and heterogeneous mixtures		**Organization of matter** – Lewis notation – Elementary particles (proton, electron, neutron) – Simplified atomic model – Relative atomic mass and isotopes – Nomenclature and notation rules – Polyatomic ions – Concept of mole	**Reaction rate** – Factors that influence reaction rate • Nature of reactants • Concentration • Surface area • Temperature • Catalysts – Rate law
	Fluids – Compressible and incompressible fluids – Pressure – Relationship between pressure and volume	**Electricity and electromagnetism** Electricity – Electrical charge – Static electricity – Ohm's law – Electrical circuits – Relationship between power and electrical energy Electromagnetism – Forces of attraction and repulsion – Magnetic field of a live wire – Magnetic field of a solenoid – Electromagnetic induction		**Chemical equilibrium** – Factors that influence the state of equilibrium • Concentration • Temperature • Pressure – Le Chatelier's principle – Equilibrium constant • Water ionization constant • Acidity and alkalinity constants • Solubility-product constant – Relationship between the pH and the molar concentration of hydronium and hydroxide ions

Cycle One	Cycle Two (compulsory program)		Cycle Two (optional program)	Cycle Two (optional program)
Secondary I and II	**Secondary III**	**Secondary IV**	**Secondary IV**	**Secondary V**
Science and Technology	**Applied Science and Technology**		**Science and the Environment**	**Chemistry**
		Transformation of energy – Law of conservation of energy – Energy efficiency – Distinction between heat and temperature	**Transformation of energy** – Relationship among work, force and displacement – Effective force – Relationship between work and energy – Relationship among potential energy, mass, acceleration and displacement – Relationship among kinetic energy, mass and velocity – Relationship among heat energy, specific heat capacity, mass and temperature	
	Waves – Frequency – Wavelength – Amplitude – Decibel scale – Electromagnetic spectrum – Deviation of light waves – Focal point of a lens	**Fluids** – Archimedes’ principle – Pascal’s law – Bernoulli’s principle **Force and motion** – Force – Types of forces – Equilibrium of two forces – Relationship among constant speed, distance and time – Distinction between mass and weight		

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