Prince Edward Island

CANADA

Education and Early Childhood Development

English Programs

Science Curriculum

Physics

Physics 521A

CURRICULUM

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Foreword

The pan-Canadian *Common Framework of Science Learning Outcomes K to 12*, released in October 1997, will assist in standardizing science education across the country. New science curriculum for the Atlantic Provinces is described in *Foundation for the Atlantic Canada Science Curriculum* (1998).

This guide is intended to provide teachers with an overview of the outcomes framework for Physics 521A. It also includes some suggestions to assist teachers in designing learning experiences and assessment tasks.

Introduction

Background

The curriculum described in *Foundation for the Atlantic Canada Science Curriculum* and in *Physics 521A* was planned and developed collaboratively by regional committees. The process for developing the common science curriculum for Atlantic Canada involved regional consultation with the stakeholders in the education system in each Atlantic province. The Atlantic Canada science curriculum is consistent with the science framework described in the pan-Canadian *Common Framework of Science Learning Outcomes K to 12*.

Aim

The aim of science education in the Atlantic provinces is to develop scientific literacy.

Scientific literacy is an evolving combination of the science-related attitudes, skills, and knowledge students need to develop inquiry, problem-solving, and decision-making abilities; to become lifelong learners; and to maintain a sense of wonder about the world around them. To develop scientific literacy, students require diverse learning experiences that provide opportunities to explore, analyse, evaluate, synthesize, appreciate, and understand the interrelationships among science, technology, society, and the environment.

Program Design and Components

Learning and Teaching Science

What students learn is fundamentally connected to how they learn it. The aim of scientific literacy for all has created a need for new forms of classroom organization, communication, and instructional strategies. The teacher is a facilitator of learning whose major tasks include

- creating a classroom environment to support the learning and teaching of science;
- designing effective learning experiences that help students achieve designated outcomes;
- stimulating and managing classroom discourse in support of student learning;
- learning about and then using students' motivations, interests, abilities, and learning styles to improve learning and teaching;
- assessing student learning, the scientific tasks and activities involved, and the learning environment to make ongoing instructional decisions;
- selecting teaching strategies from a wide repertoire.

Effective science learning and teaching take place in a variety of situations. Instructional settings and strategies should create an environment that reflects a constructive, active view of the learning process. Learning occurs through actively constructing one's own meaning and assimilating new information to develop a new understanding.

The development of scientific literacy in students is a function of the kinds of tasks they engage in, the discourse in which they participate, and the settings in which these activities occur. Students' disposition towards science is also shaped by these factors. Consequently, the aim of developing scientific literacy requires careful attention to all of these facets of curriculum.

Learning experiences in science education should vary and should include opportunities for group and individual work, discussion among students as well as between teacher and students, and hands-on/minds-on activities that allow students to construct and evaluate explanations for the phenomena under investigation. Such investigations and the evaluation of the evidence accumulated provide opportunities for students to develop their understanding of the nature of science and the nature and status of scientific knowledge.

Communicating in Science

Learning experiences should provide opportunities for students to use writing and other forms of representation as ways to learning. Students, at all grade levels, should be encouraged to use writing to speculate, theorize, summarize, discover connections, describe processes, express understandings, raise questions, and make sense of new information by using their own language as a step to the language of science. Science logs are useful for such expressive and reflective writing. Purposeful note making is an intrinsic part of learning in science, helping students better record, organize, and understand information from a variety of sources. The process of creating webs, maps, charts, tables, graphs, drawings, and diagrams to represent data and results helps students learn, and also provides them with useful study tools.

Learning experiences in science should also provide abundant opportunities for students to communicate their findings and understandings to others, both formally and informally, using a variety of forms for a range of purposes and audiences. Such experiences should encourage students to use effective ways of recording and conveying information and ideas and to use the vocabulary of science in expressing their understandings. It is through opportunities to talk and write about the concepts they need to learn that students come to better understand both the concepts and related vocabulary.

Learners will need explicit instruction in, and demonstration of, the strategies they need to develop and apply in reading, viewing, interpreting, and using a range of science texts for various purposes. It will be equally important for students to have demonstrations of the strategies they need to develop and apply in selecting, constructing, and using various forms for communicating in science.

The Three Processes of Scientific Literacy

An individual can be considered scientifically literate when he/she is familiar with, and able to engage in, three processes: inquiry, problem solving, and decision making.

Inquiry

Scientific inquiry involves posing questions and developing explanations for phenomena. While there is general agreement that there is no such thing as the scientific method, students require certain skills to participate in the activities of science. Skills such as questioning, observing, inferring, predicting, measuring, hypothesizing, classifying, designing experiments, collecting data, analysing data, and interpreting data are fundamental to engaging in science. These activities provide students with opportunities to understand and practise the process of theory development in science and the nature of science.

Problem Solving

The process of problem solving involves seeking solutions to human problems. It consists of proposing, creating, and testing prototypes, products, and techniques to determine the best solution to a given problem.

Decision Making

The process of decision making involves determining what we, as citizens, should do in a particular context or in response to a given situation. Decision-making situations are important in their own right, and they also provide a relevant context for engaging in scientific inquiry and/or problem solving.

Meeting the Needs of All Learners

Foundation for the Atlantic Canada Science Curriculum stresses the need to design and implement a science curriculum that provides equitable opportunities for all students according to their abilities, needs, and interests. Teachers must be aware of, and make adaptations to accommodate, the diverse range of learners in their class. To adapt instructional strategies, assessment practices, and learning resources to the needs of all learners, teachers must create opportunities that will permit them to address their various learning styles.

As well, teachers must not only remain aware of and avoid gender and cultural biases in their teaching; they must also actively address cultural and gender stereotyping (e.g., about who is interested in and who can succeed in science and mathematics). Research supports the position that when science curriculum is made personally meaningful and socially and culturally relevant, it is more engaging for groups traditionally under-represented in science, and indeed, for all students.

While this curriculum guide presents specific outcomes for each unit, it must be acknowledged that students will progress at different rates.

Teachers should provide materials and strategies that accommodate student diversity, and should validate students when they achieve the outcomes to the best of their abilities.

It is important that teachers articulate high expectations for all students and ensure that all students have equitable opportunities to experience success as they work toward achieving designated outcomes. Teachers should adapt classroom organization, teaching strategies, assessment practices, time, and learning resources to address students' needs and build on their strengths. The variety of learning experiences described in this guide provide access for a wide range of learners. Similarly, the suggestions for a variety of assessment practices provide multiple ways for learners to demonstrate their achievements.

Science for EAL Learners

The Prince Edward Island science curriculum is committed to the principle that learners of English as an additional language (EAL) should be full participants in all aspects of science education. English deficiencies and cultural differences must not be barriers to full participation. All students should study a comprehensive science curriculum with high-quality instruction and co-ordinated assessment.

To this end,

- schools should provide EAL learners with support in their dominant language and English language while learning science;
- teachers, counsellors, and other professionals should consider the English-language proficiency level of EAL learners as well as their prior course work in science;
- the science proficiency level of EAL learners should be solely based on their prior academic record and not on other factors;
- science teaching, curriculum, and assessment strategies should be based on best practices and build on the prior knowledge and experiences of students and on their cultural heritage;
- the importance of science and the nature of the science program should be communicated with appropriate language support to both students and parents;
- to verify that barriers have been removed, educators should monitor enrolment and achievement data to determine whether EAL learners have gained access to, and are succeeding in, science courses.

Education for Sustainable Development

Education for sustainable development (ESD) involves incorporating the key themes of sustainable development - such as poverty alleviation, human rights, health, environmental protection, and climate change - into the education system. ESD is a complex and evolving concept and requires learning about these key themes from a social, cultural, environmental, and economic perspective, and exploring how those factors are interrelated and interdependent.

With this in mind, it is important that all teachers, including science teachers, attempt to incorporate these key themes in their subject areas. One tool that can be used is the searchable on-line database *Resources for Rethinking*, found at **http://r4r.ca/en**. It provides teachers with access to materials that integrate ecological, social, and economic spheres through active, relevant, interdisciplinary learning.

Assessment and Evaluation

The terms **assessment** and **evaluation** are often used interchangeably, but they refer to quite different processes. Science curriculum documents developed in the Atlantic region use these terms for the processes described below.

Assessment is the systematic process of gathering information on student learning.

Evaluation is the process of analysing, reflecting upon, and summarizing assessment information, and making judgments or decisions based upon the information gathered.

The assessment process provides the data, and the evaluation process brings meaning to the data. Together, these processes improve teaching and learning. If we are to encourage enjoyment in learning for students now and throughout their lives, we must develop strategies to involve students in assessment and evaluation at all levels. When students are aware of the outcomes for which they are responsible and of the criteria by which their work will be assessed or evaluated, they can make informed decisions about the most effective ways to demonstrate their learning.

The Atlantic Canada science curriculum reflects the three major processes of science learning: inquiry, problem solving, and decision making. When assessing student progress, it is helpful to know some activities/skills/actions that are associated with each process of science learning. Student learning may be described in terms of ability to perform these tasks.

Assessment Techniques

Assessment techniques should match the style of learning and instruction employed. Several options are suggested in this curriculum guide from which teachers may choose, depending on the curriculum outcomes, class, and school/district policies. It is important that students know the purpose of an assessment, the method used, and the marking scheme being used. In order that formative assessment support learning, the results, when reported to students, should indicate the improvements expected.

Assessment Techniques *Continued...*

Observation (formal or informal)

This technique provides a way of gathering information fairly quickly while a lesson is in progress. When used formally, the student(s) would be made aware of the observation and the criteria being assessed. Informally, it could be a frequent, but brief, check on a given criterion. Observation may offer information about the participation level of a student for a given task, use of a piece of equipment, or application of a given process. The results may be recorded in the form of checklists, rating scales, or brief written notes. It is important to plan in order that specific criteria are identified, suitable recording forms are ready, and that all students are observed in a reasonable period of time.

Performance

This curriculum encourages learning through active participation. Many of the curriculum outcomes found in the guide promote skills and their application. There is a balance between scientific processes and content. In order that students appreciate the importance of skill development, it is important that assessment provide feedback on the various skills. These may be the correct manner in which to use a piece of equipment, an experimental technique, the ability to interpret and follow instructions, or to research, organize and present information. Assessing performance is most often achieved through observing the process.

Journal

Although not assessed in a formal manner, journals provide an opportunity for students to express thoughts and ideas in a reflective way. By recording feelings, perceptions of success, and responses to new concepts, a student may be helped to identify his or her most effective learning style.

Knowing how to learn in an effective way is powerful information. Journal entries also give indicators of developing attitudes to science concepts, processes, and skills, and how these may be applied in the context of society. Self-assessment, through a journal, permits a student to consider strengths and weaknesses, attitudes, interests, and new ideas. Developing patterns may help in career decisions and choices of further study.

Interview

This curriculum promotes understanding and applying scientific concepts. Interviewing a student allows the teacher to confirm that learning has taken place beyond simply factual recall. Discussion allows a student to display an ability to use information and clarify understanding. Interviews may be brief discussions between teacher and student, or they may be more extensive and include student, parent, and teacher. Such conferences allow a student to be pro-active in displaying understanding. It is helpful for students to know which criteria will be used to assess formal interviews. The assessment technique provides an opportunity for students whose verbal presentation skills are stronger than their written skills.

Assessment Techniques *Continued...*

Paper and Pencil (assignment or test)

These techniques can be formative or summative. Several curriculum outcomes call for displaying ideas, data, conclusions, and the results of practical or literature research. These can be in written form for display or for direct teacher assessment. Whether it is a part of learning or a final statement, students should know the expectations for the exercise and the rubric by which it will be assessed. Written assignments and tests can be used to assess knowledge, understanding, and application concepts. They are less successful assessing skills, processes, and attitudes. The purpose of the assessment should determine what form of paper and pencil exercise is used.

Presentation

The curriculum includes outcomes that require students to analyse and interpret information; identify relationships among science, technology, society, and environment; to be able to work in teams; and communicate information. Although the process can be time consuming, these activities are best displayed and assessed through presentations. These can be given orally, in written/pictorial form, by project summary (science fair), or by using electronic systems such as video or computer software. Whatever the level of complexity or format used, it is important to consider the curriculum outcomes as a guide to assessing the presentation. The outcomes indicate the process, concepts, and context for which and about which a presentation is made.

Portfolio

Portfolios offer another option for assessing student progress in meeting curriculum outcomes over a more extended period of time. This form of assessment allows the student to be central in the process. Decisions about the portfolio and its contents can be made by the student. What is placed in the portfolio, the criteria for selection, how the portfolio is used, how and where it is stored, and how it is evaluated are some of the questions to consider when planning to collect and display student work in this way. The portfolio should provide a long-term record of growth in learning and skills. This record of growth is important for individual reflection and self-assessment, but it is also important to share with others. For many students it is exciting to review a portfolio and see the record of development over time.

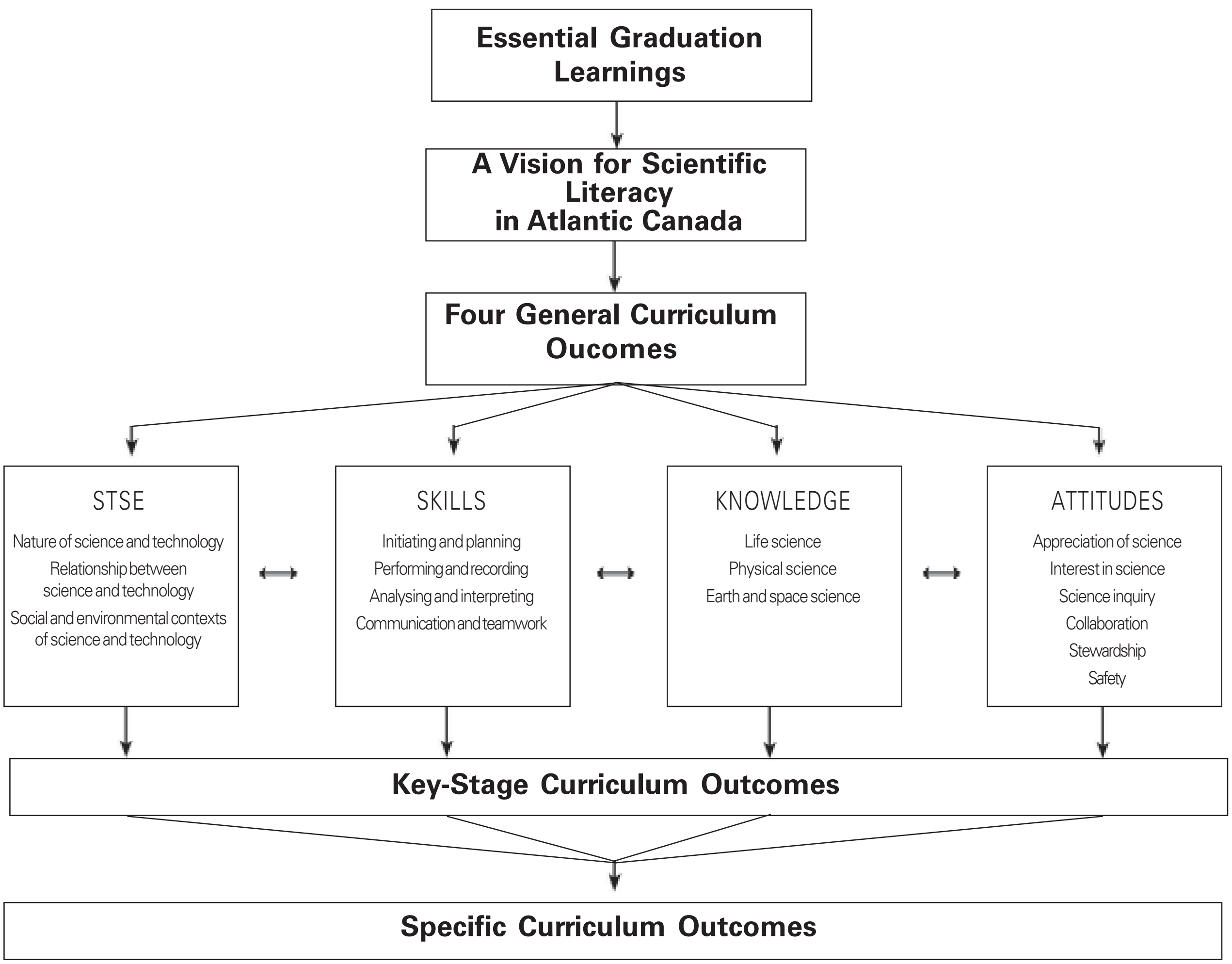
Curriculum Outcomes Framework

Overview

The science curriculum is based on an outcomes framework that includes statements of essential graduation learnings, general curriculum outcomes, key-stage curriculum outcomes, and specific curriculum outcomes. The general, key-stage, and specific curriculum outcomes reflect the pan-Canadian C*ommon Framework of Science Learning Outcomes K to 12*. The diagram below provides the blueprint of the outcomes framework.

Outcomes Framework

FIGURE 1



Essential Graduation Learnings

Essential graduation learnings are statements describing the knowledge, skills, and attitudes expected of all students who graduate from high school. Achievement of the essential graduation learnings will prepare students to continue to learn throughout their lives. These learnings describe expectations not in terms of individual school subjects but in terms of knowledge, skills, and attitudes developed throughout the curriculum. They confirm that students need to make connections and develop abilities across subject boundaries, and to be ready to meet the shifting and ongoing opportunities, responsibilities, and demands of life after graduation. The essential graduation learnings are the following:

Aesthetic Expression

Graduates will be able to respond with critical awareness to various forms of the arts and be able to express themselves through the arts.

Citizenship

Graduates will be able to assess social, cultural, economic, and environmental interdependence in a local and global context.

Communication

Graduates will be able to use the listening, viewing, speaking, reading, and writing modes of language(s) as well as mathematical and scientific concepts and symbols to think, learn, and communicate effectively.

Personal Development

Graduates will be able to continue to learn and to pursue an active, healthy lifestyle.

Problem Solving

Graduates will be able to use the strategies and processes needed to solve a wide variety of problems, including those requiring language, mathematical, and scientific concepts.

Technological Competence

Graduates will be able to use a variety of technologies, demonstrate an understanding of technological applications, and apply appropriate technologies for solving problems.

General Curriculum Outcomes

The general curriculum outcomes form the basis of the outcomes framework. They also identify the key components of scientific literacy. Four general curriculum outcomes have been identified to delineate the four critical aspects of students' scientific literacy. They reflect the wholeness and interconnectedness of learning and should be considered interrelated and mutually supportive.

Science, Technology, Society, and the Environment

Students will develop an understanding of the nature of science and technology, of the relationships between science and technology, and of the social and environmental contexts of science and technology.

Skills

Students will develop the skills required for scientific and technological inquiry, for solving problems, for communicating scientific ideas and results, for working collaboratively, and for making informed decisions.

Knowledge

Students will construct knowledge and understandings of concepts in life science, physical science, and Earth and space science, and apply these understandings to interpret, integrate, and extend their knowledge.

Attitudes

Students will be encouraged to develop attitudes that support the responsible acquisition and application of scientific and technological knowledge to the mutual benefit of self, society, and the environment.

Key-Stage Curriculum Outcomes

Key-stage curriculum outcomes are statements that identify what students are expected to know, be able to do, and value by the end of grades 3, 6, 9, and 12 as a result of their cumulative learning experiences in science. The key-stage curriculum outcomes are from the *Common Framework for Science Learning Outcomes K to 12*.

Specific Curriculum Outcomes

Specific curriculum outcome statements describe what students are expected to know and be able to do at each grade level. They are intended to help teachers design learning experiences and assessment tasks. Specific curriculum outcomes represent a framework for assisting students to achieve the key-stage curriculum outcomes, the general curriculum outcomes, and ultimately, the essential graduation learnings.

Specific curriculum outcomes are organized in units for each grade level.

Attitude Outcomes

It is expected that the Atlantic Canada science program will foster certain attitudes in students throughout their school years. The STSE, skills, and knowledge outcomes contribute to the development of attitudes, and opportunities for fostering these attitudes are highlighted in the Elaborations—Strategies for Learning and Teaching sections of each unit.

Attitudes refer to generalized aspects of behaviour that teachers model for students by example and by selective approval. Attitudes are not acquired in the same way as skills and knowledge. The development of positive attitudes plays an important role in students' growth by interacting with their intellectual development and by creating a readiness for responsible application of what students learn.

Since attitudes are not acquired in the same way as skills and knowledge, outcomes statements for attitudes are written as key-stage curriculum outcomes for the end of grades 3, 6, 9, and 12. These outcome statements are meant to guide teachers in creating a learning environment that fosters positive attitudes.

The following pages present the attitude outcomes from the pan-Canadian *Common Framework of Science Learning Outcomes K to 12* for the end of grade 12.

Common Framework of Science Learning Outcomes K to 12 Attitude Outcome Statements

By the end of grade 12, it is expected that students will be encouraged to

Appreciation of Science	Interest in Science	Scientific Inquiry
436 value the role and contribution of science and technology in our understanding of phenomena that are directly observable and those that are not **437** appreciate that the applications of science and technology can raise ethical dilemmas **438** value the contributions to scientific and technological development made by women and men from many societies and cultural backgrounds *Evident when students, for example,* • consider the social and cultural contexts in which a theory developed • use a multi-perspective approach, considering scientific, technological, economic, cultural, political, and environmental factors when formulating conclusions, solving problems, or making decisions on STSE issues • recognize the usefulness of being skilled in mathematics and problem solving • recognize how scientific problem solving and the development of new technologies are related • recognize the contribution of science and technology to the progress of civilizations • carefully research and openly discuss ethical dilemmas associated with the applications of science and technology • show support for the development of information technologies and science as they relate to human needs • recognize that western approaches to science are not the only ways of viewing the universe • consider the research of both men and women	**439** show a continuing and more informed curiosity and interest in science and science-related issues **440** acquire, with interest and confidence, additional science knowledge and skills using a variety of resources and methods, including formal research **441** consider further studies and careers in science- and explore where further science- and technology-related fields *Evident when students, for example,* • conduct research to answer their own questions • recognize that part-time jobs require science- and technology-related knowledge and skills • maintain interest in or pursue further studies in science • recognize the importance of making connections between various science disciplines • explore and use a variety of methods and resources to increase their own knowledge and skills • are interested in science and technology topics not directly related to their formal studies • explore where further science- and technology-related studies can be pursued • are critical and constructive when considering new theories and techniques • use scientific vocabulary and principles in everyday discussions • readily investigate STSE issues	**442** confidently evaluate evidence and consider alternative perspectives, ideas, and explanations **443** use factual information and rational explanations when analysing and evaluating **444** value the processes for drawing conclusions *Evident when students, for example,* • insist on evidence before accepting a new idea or explanation • ask questions and conduct research to confirm and extend their understanding • criticize arguments based on the faulty, incomplete, or misleading use of numbers • recognize the importance of reviewing the basic assumptions from which a line of inquiry has arisen • expend the effort and time needed to make valid inferences • critically evaluate inferences and conclusions, cognizant of the many variables involved in experimentation • critically assess their opinion of the value of science and its applications • criticize arguments in which evidence, explanations, or positions do not reflect the diversity of perspectives that exist • insist that the critical assumptions behind any line of reasoning be made explicit so that the validity of the position taken can be judged • seek new models, explanations, and theories when confronted with discrepant events or evidence

Common Framework of Science Learning Outcomes K to 12

Attitude Outcome Statements *continued...*

By the end of grade 12, it is expected that students will be encouraged to

Collaboration	Stewardship	Safety in Science
445 work collaboratively in planning and carrying out investigations, as well as in generating and evaluating ideas *Evident when students, for example,* • willingly work with any classmate or group of individuals regardless of their age, gender, or physical and cultural characteristics • assume a variety of roles within a group, as required • accept responsibility for any task that helps the group complete an activity • give the same attention and energy to the group's product as they would to a personal assignment • are attentive when others speak • are capable of suspending personal views when evaluating suggestions made by a group • seek the points of view of others and consider diverse perspectives • accept constructive criticism when sharing their ideas or points of view • criticize the ideas of their peers without criticizing the persons • evaluate the ideas of others objectively • encourage the use of procedures that enable everyone, regardless of gender or cultural background, to participate in decision making • contribute to peaceful conflict resolution • encourage the use of a variety of communication strategies during group work • share the responsibility for errors made or difficulties encountered by the group	**446** have a sense of personal and shared responsibility for maintaining a sustainable environment **447** project the personal, social, and environmental consequences of proposed action **448** want to take action for maintaining a sustainable environment *Evident when students, for example,* • willingly evaluate the impact of their own choices or the choices scientists make when they carry out an investigation • assume part of the collective responsibility for the impact of humans on the environment • participate in civic activities related to the preservation and judicious use of the environment and its resources • encourage their peers or members of their community to participate in a project related to sustainability • consider all perspectives when addressing issues, weighing scientific, technological, and ecological factors • participate in social and political systems that influence environmental policy in their community • examine/recognize both the positive and negative effects on human beings and society of environmental changes caused by nature and by humans • willingly promote actions that are not injurious to the environment • make personal decisions based on a feeling of responsibility toward less privileged parts of the global community and toward future generations • are critical-minded regarding the short and long-term consequences of sustainability	**449** show concern for safety and accept the need for rules and regulations **450** be aware of the direct and indirect consequences of their actions *Evident when students, for example,* • read the labels on materials before using them, interpret the WHMIS symbols, and consult a reference document if safety symbols are not understood • criticize a procedure, a design, or materials that are not safe or that could have a negative impact on the environment • consider safety a positive limiting factor in scientific and technological endeavours • carefully manipulate materials, cognizant of the risks and potential consequences of their actions • write into a laboratory procedure safety and waste-disposal concerns • evaluate the long-term impact of safety and waste disposal on the environment and the quality of life of living organisms • use safety and waste disposal as criteria for evaluating an experiment • assume responsibility for the safety of all those who share a common working environment by cleaning up after an activity and disposing of materials in a safe place • seek assistance immediately for any first-aid concerns like cuts, burns, or unusual reactions • keep the work station uncluttered, with only appropriate lab materials present

Curriculum Guide Organization

Specific curriculum outcomes are organized in units for each grade level. Each unit is organized by topic. Suggestions for learning, teaching, assessment, and resources are provided to support student achievement of the outcomes. Suggested times for each topic are also provided. Although Physics 521A is 110 hours in duration, the cummulative topic instructional time allocated is 92 hours, or 46 hours per term. The remaining 9 hours each term allows for summative assessment considerations.

The order in which the units of a grade appear in the guide is meant to suggest a sequence. In some cases, the rationale for the recommended sequence is related to the conceptual flow across the year. That is, one unit may introduce a concept that is then extended in a subsequent unit. Likewise, one unit may focus on a skill or context that will be built upon later in the year.

Some units or certain aspects of units may also be combined or integrated. This is one way of assisting students as they attempt to make connections across topics in science or between science and the real world. The intent is to provide opportunities for students to deal with science concepts and scientific issues in personally meaningful and socially and culturally relevant contexts.

Unit Organization

Each unit begins with a two-page synopsis. On the first page, introductory paragraphs provide a unit overview. These are followed by a section that specifies the focus (inquiry, problem solving, and/or decision making) and possible contexts for the unit. Finally, a curriculum links paragraph specifies how this unit relates to science concepts and skills addressed in other grades so teachers will understand how the unit fits with the students' progress through the complete science program.

The second page of the two-page overview provides a table of the outcomes from the *Common Framework of Science Learning Outcomes K to 12* that the unit will address. The numbering system used is the one in the pan-Canadian document as follows:

- 100s—Science-Technology-Society-Environment (STSE) outcomes
- 200s—Skills outcomes
- 300s—Knowledge outcomes
- 400s—Attitude outcomes (see pages 16–18)

These code numbers appear in brackets after each specific curriculum outcome (SCO).

Within each unit, the pan-Canadian outcomes are written in the context of Prince Edward Island's Physics 521A curriculum.

The Four-Column Spread

All units have a two-page layout of four columns as illustrated below. In some cases, the four-column spread continues to the next two-page layout. Outcomes are grouped by a topic indicated at the top of the left page.

Two-Page, Four-Column Spread

Page One		**Page Two**	
Topic			
Outcomes	Elaborations—Strategies for Learning and Teaching	Tasks for Instruction and/or Assessment	Resources/Notes
Students will be expected to • Specific curriculum outcome based on the pan-Canadian outcomes (outcome number) • Specific curriculum outcome based on the pan-Canadian outcomes (outcome number)	elaboration of outcome and strategies for learning and teaching elaboration of outcome and strategies for learning and teaching	*Informal/Formal Observation* *Performance* *Journal* *Interview* *Paper and Pencil* *Presentation* *Portfolio*	Provincial responsibility

Column One: Outcomes

The first column provides the specific curriculum outcomes. These are based on the pan-Canadian *Common Framework of Science Learning Outcomes K to 12*. The statements involve the Science-Technology-Society-Environment (STSE), skills, and knowledge outcomes indicated by the outcome number(s) that appear(s) in parentheses after the outcome. Some STSE and skills outcomes have been written in a context that shows how these outcomes should be addressed.

Specific curriculum outcomes have been grouped by topic. Other groupings of outcomes are possible and in some cases may be necessary to take advantage of local situations. The grouping of outcomes provides a suggested teaching sequence. Teachers may prefer to plan their own teaching sequence to meet the learning needs of their students.

Column one and column two define what students are expected to learn, and be able to do.

Column Two: Elaborations—Strategies for Learning and Teaching

The second column may include elaborations of outcomes listed in column one, and describes learning environments and experiences that will support students' learning.

The strategies in this column are intended to provide a holistic approach to instruction. In some cases, they address a single outcome; in other cases, they address a group of outcomes.

Column Three: Tasks for Instruction and/or Assessment

The third column provides suggestions for ways that students' achievement of the outcomes could be assessed. These suggestions reflect a variety of assessment techniques and materials that include, but are not limited to, informal/formal observation, performance, journal, interview, paper and pencil, presentation, and portfolio. Some assessment tasks may be used to assess student learning in relation to a single outcome, others to assess student learning in relation to several outcomes. The assessment item identifies the outcome(s) addressed by the outcome number in brackets after the item.

Column Four: Resources/Notes

This column provides an opportunity for teachers to make note of useful resources.

Kinematics *(~17 Classes)*

Introduction

Motion is a common theme in our everyday lives: birds fly, babies crawl, and we, ourselves, seem to be in a constant state of movement - running, driving, and walking. Kinematics is the study of how objects move, and as such, makes up a large part of introductory physics.

Because students learn in a variety of ways, they must be given many different opportunities to explore kinematics. The experiences should include kinesthetic learning, where students will feel the effects of different speeds and accelerations and see the difference these make in the records of their own motion. Students need to have varied experiences and time to think, reflect, assimilate, and rethink so that they own their accumulated knowledge.

Students must be encouraged to develop the vocabulary of kinematics by discussing the concepts among themselves and with the teacher. They should be required to describe and explain the motion of objects both verbally and in written and mathematical forms. Students should use algebraic and graphical analytical techniques.

Focus and Context

Inquiry and problem solving are used throughout this unit in a variety of meaningful contexts. These contexts may include examples such as skateboarding, sport, automobile motion, or any other relevant context. Students will learn best when they suggest the context. To foster connections, students must be given sufficient opportunities to observe, manipulate, discuss, predict, describe, and explain the motion of objects in various situations. Only then should problem solving in more abstract situations be undertaken.

Science Curriculum Links

Students are expected to review and extend their understanding of one-dimensional motion acquired in Science 421A, culminating in the use of one-dimensional vector representations of relative motion. The concepts developed in the study of kinematics in grade 11 will be applied to two-dimensional situations in Physics 621A.

Curriculum Outcomes

STSE	Skills	Knowledge
Students will be expected to **Nature of Science and Technology** **114-5** describe the importance of peer review in the development of scientific knowledge **Relationships between Science and Technology** **116-2** analyse and describe examples where scientific understanding was enhanced or revised as a result of the invention of a technology	*Students will be expected to* **Initiating and Planning** **212-1** identify questions to investigate that arise from practical problems and issues **Performing and Recording** **213-2** carry out a procedure, controlling the major variables and adapting the procedure where required **213-6** use library and electronic research tools to collect information on a given topic **Analysing and Interpreting** **214-5** interpret patterns and trends in data, and infer or calculate linear and nonlinear relationships among variables **Communication and Teamwork** **215-6** work co-operatively with team members to develop and carry out a plan, and troubleshoot problems as they arise	*Students will be expected to* **325-7** identify the frame of reference for a given motion **325-5** use vectors to represent position, displacement, velocity, acceleration, and force **325-2** analyse graphically and mathematically the relationships among displacement, velocity, and time

Introducing Vector Quantities
~4 Classes

Outcomes

Students will be expected to

- **use library and electronic research tools to collect information on a given topic (213-6)**
- **describe the importance of peer review in the development of scientific knowledge (114-5)**

Elaborations—Strategies for Learning and Teaching

This is the first course in which the focus is entirely on the knowledge, skills, and STSEs connections related to physics. Before delving into the topic of kinematics, students must be exposed to the breadth of physics and a formal definition of physics.
Student could be provided with a selection of newspaper or magazine articles and asked to identify how the articles relate to physics. Through class discussion, a collective operational definition of physics can be synthesized by using knowledge obtained from the articles. The collective operational definition can be later compared to a more formal definition. As a prelude, or follow-up, to this activity students should be provided with the opportunity to use library and electronic research tools to collect information about physics, or to obtain articles which they believe contain content related to physics.

- **use vectors to represent position, displacement, velocity, and acceleration (325-5)**
  - define scalar and vector quantity
  - distinguish between (among): clock reading and time interval; distance, position, and displacment; speed, velocity, and acceleration; fixed frame of reference and moving frame of reference
  - perform basic calculations to distinguish between average speed and average velocity

Students should develop a vocabulary of kinematics by being involved in discussions among themselves and with the teacher. They should be expected to describe motions appropriately, both verbally and in written form. Students should be able to distinguish between vector quantities and corresponding scalar quantities. Furthermore, students should identify how vector quantities interrelate.
A basic knowledge of frames of reference is required to develop the concept of vector quantities. Although students should be able to distinguish between fixed and moving frames of reference during this introduction, moving frames of reference will be addressed in more depth later in this unit of study (outcome 325-7).

Students need to deal with formal expression of, and operations for, vector quantities. They should realize that scalar quantities can be assigned an algebraic identifier (such as x, a, v) and that rules of operations as defined in algebra apply. However, vector quantities must be assigned a direction along with the corresponding magnitude that was calculated algebraically.

To further develop an understanding of vector quantities, students should perform basic calculations that will allow them to better grasp the relationship between speed and velocity.

Introducing Vector Quantities
~4 Classes

Tasks for Instruction and/or Assessment

Paper and Pencil

- How are distance and displacement the same? Different? (325-5)
- How are speed and velocity the same? Different? (325-5)
- Which of the fiollowing pairs yield(s) a positive displacement? Support your answer with a vector diagram.

  a) +5m, -2m b) -3m, +6m c) -4m, -2m

  (325-5, 325-7)

Presentation

- Describe for your class the relationships among the following vector quantities: position, displacement, velocity, and acceleration. (325-5)

Journal

- What does the speedometer of a car measure: speed, velocity, or both? Explain. (325-5)
- Having listened to how others view physics, describe how your perception of physics has changed. (114-5)

Performance

- Research five articles that contain content that you believe is related to physics. Describe the content that relates to physics. (213-6)

Resources/Notes

MHR *Physics,* p. 6

MHR *Physics,* pp. 30-46

Graphical and Algebraic Problem Solving
~9 Classes

Outcomes

Students will be expected to

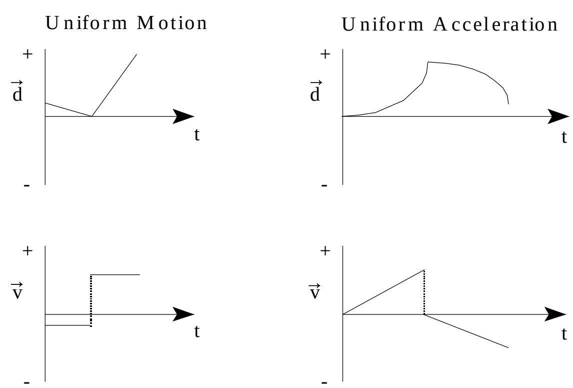
- **analyse graphically and mathematically the relationships among displacement, velocity, and time (325-2)**
- **identify questions to investigate that arise from practical problems/issues involving motion (212-1)**

Elaborations—Strategies for Learning and Teaching

The use of graphic representations such as position-time graphs and velocity-time graphs with numerical data and physical observation is an excellent method of developing student conceptual knowledge. Students should begin problem solving by qualitatively (shape of graph) relating their trials of position/time (d/t) to velocity /time (v/t) for both uniform motion and uniform acceleration. Student trials could be effectively performed and analysed graphically and numerically with a motion sensor, a constant velocity vehicle (uniform motion) and a softball (uniform acceleration, gravity).

Qualitative Graphical Analysis

Given a scenario involving uniform motion (constant velocity, zero acceleration) and uniform acceleration, students should be able to draw representative position-time graphs and velocity-time graphs. Similarly, students should be able to draw one of these graph types from the other.



It is suggested that related position-time and velocity-time graphs be aligned vertically with identical time intervals such that direct relationships can be more easily observed and interpreted. There are four possible shapes of a position-time graph representing uniform acceleration (the arc lengths of all four quadrants of a circle) and three possible shapes of a position-time graph for uniform motion (positive, negative, and zero velocity). To assist in their drawing and interpretation of these graphs, it is useful for students to recognize: position as being positive, negative, or zero; velocity as being positive, negative, or zero; and speed as increasing, decreasing, or remaining constant. This data can be organized in a chart.

Quantitative Graphical Analysis

Students should be able to determine the values of instantaneous and average velocity using line segments and tangent lines, respectively, from a position-time graph. Using a velocity-time graph, students should be able to determine the values of uniform acceleration, instantaneous acceleration, and displacement from line segments, tangent lines, and the area under the curve, respectively.

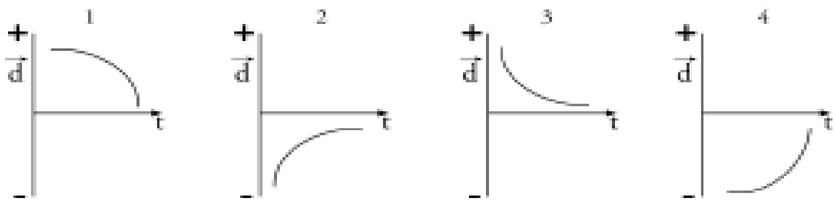
Graphical and Algebraic Problem Solving
~9 Classes

Tasks for Instruction and/or Assessment

Paper and Pencil

Graph #	Position (positive, negative, zero)	Velocity (positive, negative, zero)	Speed (increasing, decreasing, constant)
1			
2			
3			
4			

Complete the table above for each of the graphs below. Draw the corresponding velocity-time graph.



(325-2)

- Describe why the slope of a tangent line at a specified point on a curve of a position-time graph provides the instantaneous velocity at that point? (325-2)
- Describe why the area under the curve of a velocity-time graph for a given object provides the displacement of that object. Relate this description to the formula $\Delta\vec{d} = \vec{v}\,\Delta t$. (212-1, 325-2)

Performance

- Using appropriate software and a motion sensor, students could be challenged to perform a position match. (325-2)

Presentation

- Using data collected from motion trials, create a table of your data and draw d/t and v/t graphs from this information. Explain what your graphs show. (325-2)

Resources/Notes

MHR *Physics,* pp. 47-69

Graphical and Algebraic Problem Solving *continued...*
~9 Classes

Outcomes

Students will be expected to

- **analyse and describe vertical motion as it applies to kinematics (116-2)**
- **carry out a procedure, controlling the major variables and adapting the procedure where required (213-2)**
- **interpret patterns and trends in data, and infer or claculate linear and nonlinear relationships among variables (214-5)**
- **work co-operatively with team members to develop and carry out a plan, and troubleshoot problems as they arise (215-6)**

Elaborations—Strategies for Learning and Teaching

Students should conduct a laboratory investigation involving the vertical acceleration of gravity. Possible apparatus might be ticker tape timers or motion sensors. Student should communicate their resulting position-time data graphically by creating both position-time and velocity-time graphs. Percentage error should be calculated in this investigation and/or any other time where an accepted value is known. Students should be expected to attempt to justify discrepancies between their experimental value of gravitational acceleration and the accepted value.

Graphical and Algebraic Problem Solving *continued...*
~9 Classes

Tasks for Instruction and/or Assessment

Performance

- Conduct an experiment to determine the acceleration due to gravity. (116-2, 213-2, 214-5, 215-6)

Paper and pencil

- With the position-time data collected from your experiment, create a d/t and a v/t graph. Explain what your graphs show. (116-2, 213-2, 214-5, 215-6)
- Describe why your experimental value of gravitational acceleration may be different from the expected value. (116-2, 214-5, 215-6)
- Would you expect the experimental value of gravitational acceleration to be the same for all objects when an atmosphere is present? When an atmosphere is absent (vacuum)? (116-2)

Resources/Notes

MHR *Physics,* pp. 68-69

Graphical and Algebraic Problem Solving *continued...*

~9 Classes

Outcomes

Students will be expected to

- **analyse graphically and mathematically the relationships among displacement, velocity, and time** ***continued*** **... (325-2)**
- **identify questions to investigate that arise from practical problems/issues involving motion (212-1)**

Elaborations—Strategies for Learning and Teaching

Problems can be created in a variety of formats. Students could create situations involving friends, public figures, or favourite cartoon characters, and the teacher could insert kinematics problems. It is far more engaging to work with a problem in which the principal is climbing a flagpole than it is to use the traditional "a 5.0 kg body..." Students can challenge their classmates to solve problems that they create.

The formulas that students should use include the following:

$$v_{ave} = \frac{\Delta d}{\Delta t}$$

$$v_f = v_i + a\Delta t$$

$$v_{ave} = \frac{v_i + v_f}{2} \quad \text{(uniform acceleration)}$$

$$v_f^2 = v_i^2 + 2a\Delta d \quad \text{(uniform acceleration)}$$

$$\Delta d = v_i\Delta t + \frac{1}{2}a\Delta t^2 \quad \text{(uniform acceleration)}$$

Problem solving is an integral part of the study of kinematics. Teachers should approach problem solving as another tool students can use to help them understand kinematics concepts. Problems should be presented at various levels of difficulty, with at least some at the Sir Isaac Newton (SIN) test level. Good problem-solving strategies should be modelled consistently by the teacher. Reading a question a few times is suggested, as students often miss expressions such as "starting from rest." When presenting solutions, teachers should verbalize the thought process as completely as possible. Students should be encouraged to make a list of given data on the work sheet. It is also a good practice to estimate the correct answer, where possible, and to evaluate the solution according to common experience. For example, it is unreasonable to conclude that the final velocity of an automobile is 350 m/s.

A further practice which is helpful in evaluating a solution is to carry the units throughout the work. If the answer for final velocity seems to be 35.0 m/s^2, the unit itself suggests a wrong answer. The teacher should model the problem-solving technique expected from students.

Students should learn to solve what they can with the understanding that doing so may lead to something useful. They should be encouraged to check given data against the basic kinematics formulas until a formula is found for which all but one variable is known. They should then rearrange for the unknown, and solve. This methodology is a part of the systematic analysis of complex problems.

Graphical and Algebraic Problem Solving *continued...*

~9 Classes

Tasks for Instruction and/or Assessment

Journal

- Reflect on your understanding of kinematics now as compared to at the beginning of this unit. What evidence do you have to support your understanding? (325-2)

Presentation

- In groups of two, prepare kinematics problems. Write out the problem(s) and solution(s) on a separate page. Have another group try your problem(s). How is their understanding of each problem like or unlike yours? (325-2)

Paper and Pencil

Unless otherwise stated, assume a frictionless environment for each of the following scenarios:

- Alex and Raj always try to outdo each other on their skateboards. They decide to have a "hang time" contest. They begin side by side and push their boards to a speed of 5 m/s. At the same time, they jump straight up as high as they can and land on the moving boards. Alex's board goes 7.5 m before he lands, and Raj's board goes 6.0 m before he lands. How long was each boy in the air? How high did each jump? (212-1, 325-2)
- A rock and a sponge were dropped from a rooftop. The rock hit the ground in 1.4 s. The sponge took 2.0 s to fall. How high was the roof? What was the acceleration of the sponge? Why do you think there is a difference? Explain. (212-1, 325-2)
- A rock is dropped into a well. The sound of the splash is heard 4.0 s later. How deep is the well? (212-1, 325-2)
- A ball is thrown vertically with an initial upwards velocity of 44 m/s.

  What is the magnitude of the velocity of the ball when it returns to the position from which it is thrown. (212-1, 325-2)

  Would the magnitude of the velocity of the ball when it returns to the position from which it is thrown be greater or less than the answer to the above question if an atmosphere is present? Explain. (212-1, 325-2)
- A ball is launched vertically with an initial upwards velocity of 44.0 m/s. Assuming the ball lands at the launching point, find hang time, maximum height, and the time(s) when the ball has a displacement of 5.0 m. (212-1, 325-2)

Resources/Notes

MHR *Physics,* pp. 42-46, 74-89

University of Waterloo SIN Test
http://sin.uwaterloo.ca/practice.php

Vector Analysis
~2 Classes

Outcomes

Students will be expected to

- **use vectors to represent position, displacement, velocity, and acceleration *continued* ...** (325-5)
  - add and subtract parallel and perpendicular vectors algebraically
  - add and subtract all vectors graphically

Elaborations—Strategies for Learning and Teaching

Quantities with both magnitude and direction (vector quantities) cannot be adequately represented algebraically. A ray can be drawn on a Cartesian system whose length represents magnitude and orientation represents direction. There should also be a means to add, subtract, and do other operations with these quantities.

As an introduction, students could create "treasure" maps for each other in and around the school. On a city street map, it is possible to practise discrimination between distance and displacement. Students could also relate quantities such as displacement to common expressions such as, "as the crow flies."

Graphical Treatment
Students are expected to add and subtract all vectors graphically using the tip-to-tail method, a ruler to measure magnitude, and a compass to measure direction.

Algebraic Treatment
Students are expected to use the Pythagorean theorem and right-angle trigonometry, along with sketches, to add and subtract parallel and perpendicular vectors algebraically. Teachers should note that algebraic treatment of non-perpendicular vectors by resolving vectors into their horizontal and vertical components exceeds the scope of Physics 521A.

Students are expected to always communicate vector quantities with proper units and direction, and in a variety of ways. For example, a vector that points at 25° "North of West" can be restated as W25°N, 65° "West of North", or N55°W. Vector direction should also be represented graphically.

Vector Analysis
~2 Classes

Tasks for Instruction and/or Assessment

Paper and Pencil

- Caroline and Erin planned to meet at the shopping mall. Caroline left her home and walked 4 blocks north, 2 blocks east, and 2 more blocks north to reach the mall. Erin left her house and walked 2 blocks south, 3 blocks west, and 3 more blocks south. Draw a careful vector diagram of both motions and answer the following questions:
  - What distance did each girl walk?
  - Which girl is farthest in a straight line from the mall (direction in degrees)?
  - What is the straight line distance between Caroline's home and Erin's home?

  Note: *All distances may be expressed in blocks.* (325-5)
- Mark rode his personal water craft at a constant speed of 30 km/h directly across a river running at 5 km/h downstream. What is Mark's velocity relative to the bank? Solve graphically and algebraically. (325-5)
- The sum of two vectors is zero. What can you say about the magnitude and direction of the two initial vectors? (325-7)

Presentation

- Create a short narrative involving several of your friends, using the following displacements. List three questions you could ask if the following were points on a test question:
  a. 10 km east
  b. 5.0 km south
  c. 8.0 km west
  d. 3.8 km northwest (325-5)

Resources/Notes

MHR *Physics,* pp. 90-103

Relative Motion
~2 Classes

Outcomes

Students will be expected to

- **identify the frame of reference for a given motion to distinguish fixed and moving frames (325-7)**
- **identify questions to investigate that arise from practical problems/issues involving motion (212-1)**

Elaborations—Strategies for Learning and Teaching

Skateboard physics is a meaningful context for this concept. In Physics 521A, this topic should be approached qualitatively in only one dimension. For example, if a skateboarder goes by, how does her motion appear against a fixed background? How does the background appear to the boarder? How does the boarder's motion appear to an observer moving in the same direction? In the opposite direction? It is important that the student defines "frame of reference" as the position from which motion is observed. Furthermore, it is important that the context provided by students and teachers is practical, and that opportunities exist to further explore the context.

As an interesting activity, students could explore frames of reference by using a motion sensor and two dynamics carts or other moveable objects on a lab table surface. Students could examine the velocity of one cart/object relative to the other under the following conditions:

- one cart stationary
- both carts moving in the same direction at the same and different speeds
- both carts moving in opposite directions at the same and different speeds

Students should develop a vocabulary of kinematics by being involved in discussions among themselves and with the teacher. They should be expected to describe motions appropriately, both verbally and in written form. For example, Car A is behind Car B travelling East at 55 km/h relative to Earth. Car B is travelling East at 45 km/h relative to Earth. What is the velocity of Car A relative to Car B? (Reference point is Car B; therefore, Car A is being observed from the location of Car B.)

Conceptually: Car A appears to be travelling at 10 km/h East relative to Car B; therefore, v_{AB} = 10 km/h (let East = positive).

Alternatvely, Car B appears to be travelling at10 km/h West relative to Car A. v_{BA} = - 10 km/h (let East = positive).

Conventions that can be used for communication purposes include:

v_{AB} (velocity of Car **A** relative to Car **B**)
v_{BA} (velocity of Car **B** relative to Car **A**)
v_{AE} (velocity of Car **A** relative to **E**arth)
v_{BE} (velocity of Car **B** relative to **E**arth)

Students could respond to questions such as, Why is the calculation of relative motion important?. With reference to the example provided above regarding Car A and Cab B, students can be further challenged with practical problems by using the relative velocity (passing velocity) with the kinematic equations to calculate the time elapsed and displacement while passing (the definition of passing will need to be elucidated).

Relative Motion
~2 Classes

Tasks for Instruction and/or Assessment

Informal Observation

- Teachers can use the rubric below to assess group activity related to the skateboard questions: (325-7)

Motion Activities

	Student 1	Student 2	Student 3	Student 4
Uninvolved				
Participating				
Contributing				
Leading				

Paper and Pencil

- A truck travelling at 95.0 km/h passes a car travelling in the same direction at a speed of 82 km/h. (212-1, 325-7)

  -What is the speed of the car relative to the truck? The truck relative to the car?
- A truck travelling at 95.0 km/h passes a car travelling in the opposite direction at a speed of 82 km/h. (212-1, 325-7)

  -What is the velocity of the car relative to the truck? The truck relative to the car?
- A scooter is travelling west at 75.0 km/h. If a car is 25.0 km behind the scooter, how long will it take the car to catch up if it travels at an average velocity of 95 km/h? (212-1, 325-7)
- A ship is travelling alongside a dock at 5.0 km/h West relative to the dock. If the ship's captain walks toward the stern of the ship at 3.5 km/h, what is the captain's speed relative to a stationary observer on the dock? Relative to an observer travelling West at 4.0 km/h? Relative to an observer travelling East at 4.0 km/h? (212-1, 325-7)
- A car travelling at 90.0 km/h is passed by a 4.5 m truck, travelling in the same direction, in 1.9 seconds. What is the velocity of the truck relative to the car? Relative to Earth? (Please define your interpretation of "passing" when communicating your relative velocities). (212-1, 325-7)

Resources/Notes

MHR *Physics,* pp. 104-105

Dynamics *(~19 Classes)*

Introduction

From real life experiences, students know that objects speed up, slow down, and change direction, and they accept this as a matter of course. Dynamics is the study of the factors that cause such changes, that is, why an object moves the way it does. It is a logical extension of kinematics, and this unit should pick up questions arising naturally from the previous unit's study of the motion of objects. Students could begin by investigating the effects of one-dimensional forces on themselves and on objects, and through the application of Newton's laws, use their knowledge of dynamics to move on to an analysis of systems.

Focus and Context

As in the kinematics unit, students should draw on their own experiences in attempting to describe and analyse forces. Familiar forces students feel acting on themselves in cars, on amusement park rides, and during sports activities should be discussed and analysed. A simple activity such as measuring with a spring scale the force needed to start and continue to pull a student along the floor in a wagon or freight dolly can lead to discussion of the outcomes of applied force: acceleration, and overcoming friction. Activities with dynamics carts would then allow students to investigate, measure, manipulate, and predict relationships among force, mass, and acceleration. This could lead to many opportunities for individual study and research projects involving design and operation of such devices as seat belts, airbags, helmets, and sports equipment—all with a view to making connections among the design, principles of physics, and society's concern and influence (an STSE connection.)

Science Curriculum Links

This unit completes the study of motion begun in Science 421A. It leads students to the more sophisticated concepts of momentum and energy that are necessary for the study of interactions between masses.

Curriculum Outcomes

STSE	Skills	Knowledge
Students will be expected to	*Students will be expected to*	*Students will be expected to*
Nature of Science and Technology 115-3 explain how a major scientific milestone revolutionized thinking in the scientific communities **Relationships between Science and Technology** 116-2 analyse and describe examples where scientific understanding was enhanced or revised as a result of the invention of a technology 116-5 describe the functioning of domestic and industrial technologies, using scientific principles 116-6 describe and evaluate the design of technological solutions and the way they function, using scientific principles 116-7 analyse natural and technological systems to interpret and explain their structure and dynamics **Social and Environmental Contexts of Science and Technology** 117-2 analyse society's influence on scientific and technological endeavours	**Initiating and Planning** 212-3 design an experiment, identifying and controlling major variables 212-8 evaluate and select appropriate instruments for collecting evidence, and appropriate processes for problem solving, inquiring, and decision making **Performing and Recording** 213-2 carry out procedures, controlling the major variables and adapting or extending procedures where required 213-3 use instruments effectively and accurately for collecting data 214-14 construct and test a prototype of a device, and troubleshoot problems as they arise **Analysing and Interpreting** 214-3 compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flow-charts, tables, graphs, and scatter plots 214-5 interpret patterns and trends in data, and infer or calculate linear and non-linear relationships among variables	325-5 use vectors to represent position, displacement, velocity, acceleration, and force 325-8 apply Newton's laws of motion to explain inertia; the relationship among force, mass, and acceleration; and the interaction of forces between two objects

Dynamics Introduction
~6 Classes

Outcomes

Students will be expected to

- **explain how a major scientific milestone revolutionized thinking in dynamics (115-3)**
  - explain Galileo's concept of inertia
  - explain the meaning of inertial mass and gravitational mass

- **use vectors to represent forces (325-5)**
  - define dynamics, kinematics, and mechanics
  - distinguish between mass and weight
  - draw free-body diagrams representing contact and non-contact forces (F_n, F_f, F_a, F_g)
  - explain what is meant by *net* force (F_{net}) and apply it to several situations

Elaborations—Strategies for Learning and Teaching

Using Galileo's concept of inertia, students should be able to refute Aristotle's erroneous claim that objects travel at constant speed when acted upon by a constant force - a claim that was broadly accepted for approximately 2000 years. This discussion provides an excellent context in which to more formally define force, and more broadly, dynamics.

The video *Galileo, The Challenge of Reason* is an excellent dramatization of the conflict between codified thought and experimentally verified science. Teachers might want to plan on a second viewing for detailed observation. For later discussion, students should make note of observations or questions that arise during viewing. For example, how did Aristotle's view of the universe come to be the only Greek view approved by the seventeenth century Christian church? What other Greek views had been proposed? Were there African, Oriental, or other theories at that time? What is the apparent role of women in this society? Why were clerics reluctant to accept what they plainly saw demonstrated?

Students should investigate the use of vectors and vector diagrams to describe the forces that affect the linear motion of a variety of things, such as airplanes, birds, cars, and boats. The concept of free-body diagrams should be introduced. This analytical tool isolates an object in space and shows vectors representing all forces acting on it.

Students should perform a laboratory exercise involving F_a and F_g by using a block hanging from a spring scale. Students should be able to determine the reading of the spring scale (or force sensor) and draw a diagram of the forces acting on the block. They should look at three situations involving the block: hanging free, being gently raised, and being gently lowered. They should determine the net force in each case.

As a logical progression, students should draw free body diagrams involving F_n, F_f, F_a, and F_g. For example, an object resting on a table top in static equilibrium with a horizontally applied force (using spring scale or force sensor) would require vector representation of these four forces. As a continuation from this exercise, students could horizontally accelerate an object, draw the resulting free-body diagram, and identify the direction of the non-zero net force. The focuses should be on the vector representation of all forces acting on an object, and on determining the relative sum of all forces acting on the object by viewing each dimension independently.

Dynamics Introduction
~6 Classes

Tasks for Instruction and/or Assessment

Performance

- Demonstrate appropriate use of the spring scale (zeroing and reading). (325-5, 116-6)
- Draw free body diagrams to represent all the forces acting in each of the situations (static equilibrium, dynamic equilibrium, acceleration) explored in your lab activity. (325-5)

Journal

- Based on the following scenario, if you were Galileo's friend, how would you help defend him?

  HEADLINE: GALILEO A COPERNICAN!
  DATE LINE: ROME

  Officers of the Inquisition have brought the famous scholar Galileo Galilei to Rome for questioning about his recent book. With his devil's sceptre (or telescope, as he calls it) he has observed the heavens, and in particular, claims to have seen the moon of Jupiter. He must prove to the Tribunal that what he has written is consistent with the Universal View held by the Holy Roman Church. (115-3)

Presentation

- Research particular milestones individually. Report in small groups. Finally, as a class, assemble a time line from the individual reports. (115-3)
- Present a mock trial of Galileo. (115-3)
- For a newspaper's weekend edition, write an article on your dynamics research involving a technology and changed scientific thinking. (115-3)

Resources/Notes

MHR *Physics,* pp. 126-129

video: *Galileo, The Challenge of Reason* (Media Services, Learning Resources and Technology)

MHR *Physics,* pp. 128-136
pp. 145-146

Newton's Laws
~10 Classes

Outcomes

Students will be expected to

- **use vectors to represent forces *continued...*** (325-5)
  - differentiate between static and kinetic frictional forces
  - perform computations involving friction, normal force, and the coefficient of friction in one-dimension

- **design an experiment, identifying and controlling major variables** (212-3)
  - design an experiment to determine the coefficient of static and kinetic friction
  - design an experiment to explore kinetic friction and contact area.

Elaborations—Strategies for Learning and Teaching

Over time, students should develop an understanding of the nature of friction and its effect on dynamic systems. They should understand the difference between static and dynamic (kinetic) friction, and the relationship between friction, normal force, and the coefficient of friction for both static and kinetic situations.

$$F_f = \mu F_n$$

As part of Newton's third law addressed in outcome 325-8, students can engage in discussions regarding the ability of $F_{f(static)}$ to obtain a magnitude that is less than the maximum value, depending upon the magnitude of the force applied.

Students should distinguish between data collection and scientific inquiry. Data collection is a mechanical operation. Data could be collected by computerized systems or directly by a student.

Students should design an experiment in which blocks of wood are pulled across a surface by a spring scale, or force sensor. Students should decide what trials need to be carried out to explore the relationship between the force of kinetic friction and the normal force, and also between kinetic friction and surface area in contact. Trials must be done in such a manner that the applied force is just great enough to overcome friction and continue the motion of the block without accelerating it. Normal force could be controlled by using blocks with different surface area loaded to the same total mass. Students might want to do some trial-and-error runs to determine parameters, such as what range of masses can best be moved at a constant low speed. Free body diagrams should be used for all situations. Students should write down questions for later investigation and discussion. For example, what is the net force when the block is moving at constant speed? What is happening as the block is started up and then brought to a stop?

Newton's Laws
~10 Classes

Tasks for Instruction and/or Assessment

Performance

- Measure various factors that could affect the size of a friction force. These should include normal force, surface area in contact, and types of surfaces in contact. (212-3, 325-5)
- Design an experiment to determine the coefficient of static and kinetic friction. Once your plan has been approved, carry out the procedure. (212-3, 325-5)

Paper and Pencil

- Make an original puzzle that includes the following terms and their definitions: acceleration, inertia, applied force, net force, normal force, static friction, kinetic friction, and coefficient of friction. (325-5, 325-8)
- Does the coefficient of friction change with the normal force? Does the frictional force change? Explain. (325-5)
- A force of 20.0 N is applied horizontally to an object, causing it to travel with constant velocity. What is the mass of the object if the coefficient of kinetic friction is 0.11? (325-5)

Resources/Notes

MHR *Physics,* pp. 137-144

MHR *Physics,* pp. 137-144

Newton's Laws *continued...*
~10 Classes

Outcomes

Students will be expected to

- **apply Newton's laws of motion to explain inertia; the relationships among force, mass, and acceleration; and the interaction of forces between two objects (325-8)**
  - explain, using Newton's first law, inertial frames of reference

Elaborations—Strategies for Learning and Teaching

Students should recognize that the external force mentioned in Newton's first law refers to an external force that is in addition (net force) to the existing forces that render an object in static or dynamic equilibrium.

Students should use Newton's first law to explain inertial frames of reference only. A variety of demonstrations can be used to reinforce the concept of inertia, such as mimicing the motion of a driver during braking; showing the reluctance of objects at rest to move when a table cloth is quickly removed from underneath; hitting the handle of an axe against a hard surface to securely tighten the head to the handle; and catching a coin that was resting on your elbow.

For an enrichment, teachers may wish to discuss non-inertial frames of reference and how Newton's laws fail to describe motion in this context. For example, a ball is stationary relative to a platform undergoing uniform motion. If the platform suddenly accelerates negatively, the ball will begin to move relative to the platform. The motion of the ball relative to the platform (non-inertial frame of reference) cannot be explained using Newton's laws as no net external force caused the relative motion of the ball.

- **apply Newton's laws of motion to explain inertia; the relationships among force, mass, and acceleration; and the interaction of forces between two objects *continued...* (325-8)**
  - apply Newton's second law to qualitatively and quantitatively describe the relationships among force, mass, and acceleration in one dimension

In developing the relationships among force, mass, and acceleration, students could first be engaged in the laboratory outcomes on the following two-page spread where the proportional relationship between net force and acceleration is identified graphically. From this laboratory activity, Newton's second law can be formalized. Students should be able to qualitatively discuss - using the proportionality terms "directly" and "indirectly" - the effect on the variables pertaining to Newton's second law when other variables are altered (e.g. doubled, tripled, halved, increased). Newton's first law should be integrated with the second law by asking students, Why doesn't a more massive ball (greater net force) fall with greater acceleration than a less massive ball? This provides a context in which to discuss the relationship between inertia and mass. Quantitatively, students are expected to relate the unit of force (Newton, N) to the fundamental units (kg m/s^2) from which it is defined. Students are expected to perform calculations with Newton's second law formula (Fnet = ma), and also integrate all the kinematic formulas with the Newton's second law formula. They are expected to apply Newton's laws to situations where forces are applied horizontally and vertically. They should be aware that weight is the gravitational force. Furthermore, they are expected to describe these relationships qualitatively (conceptually).

Newton's Laws *continued...*

~10 Classes

Tasks for Instruction and/or Assessment

Journal

- Comment on the following statement:

  The term "newton" is merely a convenient shorthand for the actual dimension of inertially defined force. (325-8)
- Describe why seatbelts and headrest are the result of applying Newton's first law to safety features (refer to the seatbelt mechanism in your describtion). (325-8)

Paper and Pencil

Assume a frictionless environment unless otherwise stated.

- Design a problem that uses Newton's second law. Include an answer sheet. Exchange your problem with that of another student. (325-8)
- What force is necessary to accelerate a 1200 kg car along a horizontal surface from rest to 130 km/h in 8.0 s? (325-8)
- What mass would a sled on ice have if it requires a horizontal force of 100.0 N to change its velocity from 30.0 km/h to 120 km/h in 5.0 s? (325-8)
- What is the acceleration of a block having a mass of 0.5 kg which is being pulled in opposite directions by two children. Sean is pulling with a force of 3.0 N to the left, and Diane is pulling to the right with 5.0 N. How far will it move in 3.0 s? (325-8)
- Two objects of different weight fall from a roof. Why do they hit the ground below at the same time if one falls with a greater downward force than the other? (325-8)
- What force must be applied to an object to double its acceleration? To achieve a third of the original acceleration? (325-8)
- If a constant net force is applied to an object, how would the object's acceleration change if it maintained only a quarter of its original mass? (325-8)
- An object is accelerated at a rate of 3 m/s^2 when a force of 50.0 N is applied horizontally. If the mass of the object is 15.0 kg, what is the magnitude of the frictional force acting on the object? (325-8)

Resources/Notes

MHR *Physics,* pp. 154-159

MHR *Physics,* pp. 160-167

Newton's Laws *continued...*
~10 Classes

Outcomes

Students will be expected to

- **evaluate and select appropriate instruments for collecting evidence, and appropriate processes for problem solving, inquiring, and decision making (212-8)**
- **carry out procedures, controlling the major variables and adapting or extending procedures where required (213-2)**
- **use instruments effectively and accurately for collecting data (213-3)**
- **compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flowcharts, tables, graphs, and scatter plots (214-3)**
- **interpret patterns and trends in data, and infer or calculate linear and non-linear relationships among variables (214-5)**

Elaborations—Strategies for Learning and Teaching

Please note that outcomes 212-8, 213-2, 213-3, 214-3, and 214-5 are discussed as a group.
Students should perform a laboratory investigation to identify the relationships among force, mass, and acceleration. Whatever the method used for Newton's second law experiment (from three-wheel dynamics carts to an air track), good results can be obtained if care is taken in setting up the trials.

The gravitational force on a hung mass is used as a driving method. The hung mass is accelerating the combined mass (mass of system) that includes the cart and the hung mass. To do trials in which mass is kept constant, the combined mass must not change, and mass must be moved from the cart to the hanger to change the driving force. This is an excellent opportunity for students to learn to control variables and minimize errors. Furthermore, for more accurate results, a force sensor can be placed on the dynamics cart so that applied force (not the weight of the hung mass) is compared to the cart's acceleration. Placing the force meter on the dynamics cart results in the frictional forces present in the pulley being eliminated as a source of error.

Students can obtain the average force during acceleration from the force sensor (F_{net}, assuming friction is negligible), and the acceleration of the cart from an analysis of the slope of the linear fit of the v/t graph (motion sensor data). The resulting force and acceleration data for each trial can be plotted on an "F_{net}" vs. "a" graph. The graph should be linear, indicative of the proportional relationship between "F_{net}" and "a". Furthermore, the slope should equal the mass of the system. Students can later find the mass of the system and compare it to their experimental value. Possible discrepancies could be discussed along with a percent difference calculation.

During the course of an investigation, student lab groups could be asked to make periodic progress reports and share ideas.

Newton's Laws *continued...*

~10 Classes

Tasks for Instruction and/or Assessment

Informal Observation

- It is appropriate here for the teacher to apply a checklist of skills that students should develop. Possible skills might include using instruments correctly; doing enough trials for a good, average value; and recording the results in an appropriate table. (325-8)

Performance

- Conduct a laboratory investigation of the relationships among force, mass, and acceleration. (325-8, 212-8, 213-2, 213-3)
- Create many situations for the carts and track, and explore them on the track. Keep a list/chart of each situation explored on the track. Include force, mass, acceleration, and general comments. (325-8)

Paper and Pencil

- Write a thorough report on your lab. Analyse and interpret the data in raw form and graphically. From the raw data, it is possible to see whether the relationship is linear or exponential, direct or inverse. Graphs of a α F for trials where mass is kept constant, a 1/m for trials where applied force is kept constant, and a F/m for all trials all lead to the equation a = F/m. Interpreting the numerical value and the dimensions (unit) of the slope on each graph, you realize that F = (1)ma only if Newtons of force are dimensionally the same as kg*m/s^2. (325-8, 212-3, 212-8, 213-2, 213-3, 214-3, 214-5)

α

Resources/Notes

MHR *Physics,* pp. 160-167

Newton's Laws *continued...*

~10 Classes

Outcomes

Students will be expected to

- **apply Newton's laws of motion to explain inertia; the relationships among force, mass, and acceleration; and the interaction of forces between two objects (325-8)**
  - apply Newton's third law to identify action-reaction forces between two objects
  - apply Newton's third law to calculations involving two objects acting in one dimension
  - apply Newton's third law to explain weight vs. weightlessness, air resistance, and terminal velocity

Elaborations—Strategies for Learning and Teaching

Students should be expected to identify and describe action-reaction forces in a variety of situations. It is sometimes difficult for students to imagine that for every force there is an equal and opposite force. To demonstrate this concept, two force sensors, or spring scales, can be attached together. Students should take turns pulling at both ends to observe that the measurements recorded on the instruments will always be identical.

Once students have accepted Newton's third law, an interesting way to deepen their understanding of how the third law relates to the first and second laws is to pose the question, If for every force there exist an equal and opposite force, then how can an object at rest move if a net force is required for motion? Eventually, direct the students' attention to the fact that the third law describes action-reaction forces between two objects, whereas the first and second laws isolate an object and allow us to focus on all forces that exist on that individual object. Students can then observe, with the use of free-body diagrams, how a net force can exist on an individual object, thus causing a change in motion (acceleration).

Students are expected to perform calculations involving two masses acting in one direction. Elevator problems provide an excellent context in which to investigate Newton's third law, where students must distinguish between weight and apparent weight. Furthermore, students should be expected to explain free fall, how air resistance is different than surface resistance, and terminal velocity. Students are expected to connect action-reaction forces to Newton's first and second laws along with the kinematic equations and concepts from unit one.

Calculations and concepts related to multiple masses (more than two) and problems involving two dimensions exceed the expectations of Physics 521A, and will be addressed in Physics 621A. Examples of Physics 621A problems include Atwood's machine and "train" problems involving the linkage forces that exist between multiple box cars.

Newton's Laws *continued...*

~10 Classes

Tasks for Instruction and/or Assessment

Journal

- Does the speed of an object affect friction? Discuss this. (325-8)
- "The faster you go, the more friction there is." Identify a situation for which this statement is true. Explain. (325-8)

Paper and Pencil

- What would be the tension in a cable lifting an elevator and a person with a combined mass of 575 kg moving (a) upward at a rate of 5.0 m/s^2 and (b) downward at a rate of 5.0 m/s^2? (325-8)
- Which of the following will have the greatest terminal velocity? Explain.

  a. free-fall vs. parachute b. spread eagle vs. knife (325-8)

Performance

- In groups, identify and discuss situations that are described by Newton's third law (e.g. recoil of a rifle, rocket propulsion). Select one situation to report on to the class. (325-8)

Resources/Notes

MHR *Physics,* pp. 177-188

Momentum Introduction
~3 Classes

Outcomes

Students will be expected to

- **apply Newton's laws of motion to explain inertia; the relationships among force, mass, and acceleration; and the interaction of forces between two objects *continued...*** (325-8)
  - define linear momentum
  - define impulse and apply it to Newton's second law
  - apply impulse-momentum theorem in problem situations
- **analyse and describe examples where knowledge of the dynamics of bodies was enhanced or revised as a result of the invention of a technology** (116-2)
- **analyse the influence of society on scientific and technological endeavours in dynamics** (117-2)
- **describe and evaluate the design of technological solutions and the way they function, using scientific principles** (116-6)
- **analyse natural and technological systems to interpret and explain their structure and dynamics** (116-7)
- **describe the functioning of technical devices based on the principles of momentum** (116-5)
- **construct and test a prototype of a device, and troubleshoot problems as they arise** (214-14)

Elaborations—Strategies for Learning and Teaching

Students should be introduced to the concepts of impulse and momentum as a development of Newton's second law. Students might see $F\Delta t = mv_2 - mv_1$ as a more logical expression since it isolates the "cause" product at the left. Newton's "quantity of motion," or momentum, might be more meaningful in this context. Students should relate these concepts qualitatively to a variety of situations.

Challenging students to find examples of momentum drawn from daily experience is fun for them and gives students ownership of the task. Some student-generated questions might include the following:

- Why do hockey helmets have rigid foam liners, not soft?
- Why is a gym floor "floating" on a cork layer?
- How are running shoes different from skateboard shoes?
- How does an impact wrench work?
- What happens to a tennis ball during impact?
- How does a 5 km/h bumper on a car work?
- Why is it vitally important that a person be 30.0 cm from an airbag when it inflates? What is the airbag designed to do?

An examination of automobile safety features (e.g., crumple zones, ABS braking) and related STSE issues provides a powerful context in which to investigate and discuss dynamics. Students should be invited to propose their own questions (e.g., questions about the advantages and disadvantages of ABS braking systems, all-wheel drive, or other recent technological advances). Issues could be examined from different perspectives (e.g., the producer, the consumer, and the medical community). Students should apply more sophisticated concepts as they progress in the course, while maintaining a focus on the issue. They could consider other elements of automobile safety besides ABS brakes, and they might investigate how these elements function from a physics perspective.

Students could interpret the structure and function of a wide range of systems, such as the human skeleton, spoilers on racing cars, bicycle helmets, tapered fishing poles, other sporting equipment, and prosthetic devices. During discussions, students should explore, qualitatively and in terms of forces, questions such as, Why would the bottom vertebrae be bigger than the top? What is the purpose of a spoiler on a race car (what does it do)? How does the bicycle helmet spread the force of impact?

Students could be asked to construct a bumper for a dynamics car with a goal of minimizing the total force applied to the car during impact. They could be given criteria such as total mass, dimensions, materials, and height and angle from which the car will be released.

Momentum Introduction
~3 Classes

Tasks for Instruction and/or Assessment

Performance

- Perform an experiment to investigate the impulse-momentum theorem. (325-8)
- Research one example of a technology of your choice, and prepare an article for publication in a science magazine or your school's science newsletter that explains the application of the principles of impulse and momentum. (116-5)
- Design, construct, and test a safety bumper for a dynamics car to determine which student's bumper design provides the *lowest force* during impact. (214-14)

Paper and Pencil

- Prepare a report that explains a single example of automobile technology that includes the following:
  - the influence of automobile safety on society
  - the design of the example that you pick with respect to the way it functions (117-2, 116-6)
- How fast must a 350 kg car travel to have the same momentum as a 1550 kg car? (325-8)
- The brakes exert a 740.0 N force on a 15 600 N car that is travelling at 25.0 m/s. If the car comes to a stop, find the car's mass, the change in the car's momentum, the amount of time required to bring the car to rest, and the impulse that acted on the car to bring it to rest. (325-8)
- A 2.72 kg bowling ball falls from the height of 1.2 m. Find the momentum when it reaches the floor, the impulse required to bring it to rest, and the average force exerted on the ball if it lands on a 5.0 cm dense foam pad (assume a constant stopping force).

Journal

- Write an entry in your journal explaining what you have learned about how dynamics concepts apply to automobile safety. This is your opportunity to make personal notes. The journal entry may reflect progress or frustration. It may help you to verbalize your problem(s) to your teacher. (117-2, 116-6)

Presentation

- Draw a cartoon that explains one of the concepts used in your study of dynamics. Be sure that it is simple, specific, and short so the reader can learn from it. (325-8, 116-2, 115-3)
- Prepare a short oral presentation from the list of topics generated in class. This is an exploratory exercise. Expectations are that you are questioning, analysing, describing, and/or evaluating the structure using the scientific principles with which you are familiar. Use a KWL chart. (116-7)

Resources/Notes

MHR *Physics,* pp. 195-205

Momentum and Energy *(~19 Classes)*

Introduction

When two or more objects are considered at once, a system is involved. To make sense of what happens between parts of a system, the concepts of momentum and energy are needed. Students have seen many situations where a system of objects is involved. After the students have had a chance to look at the concepts of momentum and energy in familiar contexts, they should apply the concepts to less familiar situations. Students could begin by describing the changes they feel on various playground equipment or amusement park rides and developing an explanation for these changes using the vocabulary and concepts of energy and momentum. Eventually, their understanding of these events will involve the conservation laws, which will allow them to describe, explain, and predict the outcomes of many one-dimensional interactions.

Focus and Context

All students will be familiar with a playground environment. This context provides a wealth of examples of energy transformation and two-body interactions. Other relevant contexts, such as sport, could be used in individual schools. By reviewing their experiences and collecting data, students can begin inquiring and discussing. By examining playground events, students will discover the need to learn the concepts of momentum and energy. There is increasing social concern about playground safety. Students could be expected to pose questions and identify safety concerns by answering such questions as, How high is too high? or What material is appropriate? and to develop a plan to answer their questions. Then they will be able to move from this familiar context to other situations where the concepts can be applied.

Science Curriculum Links

In grade 8 science, students have explored the movement of objects in terms of balanced and unbalanced forces. They have also described quantitatively the relationships among force, area, and pressure.

In Physics 621A, students should develop a more precise understanding of momentum and energy and learn to evaluate situations using these concepts.

In Chemistry 621A, students will be analysing closed, isolated systems in thermodynamics with regard to energy transformations between chemical potential and heat.

Curriculum Outcomes

STSE

Students will be expected to

Nature of Science and Technology

114-9 explain the importance of communicating the results of a scientific or technological endeavour using appropriate language and conventions

115-5 analyse why and how a particular technology was developed and improved over time

Relationships Between Science and Technology

116-4 analyse and describe examples where technologies were developed based on scientific understanding

116-6 describe and evaluate the design of technological solutions and the way they function, using principles of energy and momentum

Social and Environmental Contexts of Science and Technology

118-8 distinguish between questions that can be answered by science and those that cannot and between problems that can be solved by technology and those that cannot

Skills

Students will be expected to

Initiating and Planning

212-3 design an experiment, identifying and controlling major variables

212-8 evaluate and select appropriate instruments for collecting evidence, and appropriate processes for problem solving, inquiring, and decision making

Performing and Recording

213-2 carry out procedures, controlling the major variables and adapting or extending procedures where required

213-3 use instruments effectively and accurately for collecting data

Analysing and Interpreting

214-3 compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots

214-5 interpret patterns and trends in data, and infer or calculate linear and non-linear relationships among variables

214-7 compare theoretical and empirical values, and account for discrepancies

214-11 provide a statement that addresses the problem or answers the question investigated in light of the link between data and the conclusion

Knowledge

Students will be expected to

326-3 apply quantitatively the laws of conservation of momentum to one-dimensional collisions and explosions

325-9 analyse quantitatively the relationships among force, displacement, and work

325-10 analyse quantitatively the relationships among work, time, and power

326-1 analyse quantitatively the relationships among mass, height, speed, and heat energy using the law of conservation of energy

326-5 describe quantitatively mechanical energy as the sum of kinetic and potential energies

326-6 analyse quantitatively problems related to kinematics and dynamics using the mechanical energy concept

326-7 analyse common energy transformation situations using the work-energy theorem

326-4 determine which laws of conservation of energy or momentum are best used to solve particular real-life situations involving elastic and inelastic collisions

326-8 determine the percent efficiency of energy transformations

Technological Implications

Outcomes

Students will be expected to

- **analyse and describe examples where energy- and momentum-related technologies were developed and improved over time (115-5, 116-4)**
- **describe and evaluate the design of technological solutions and the way they function using principles of energy and momentum (116-6)**
- **analyse and describe examples where technological solutions were developed based on scientific understanding (116-4)**
- **explain the importance of using appropriate language and conventions when describing events related to momentum and energy (114-9)**

Elaborations—Strategies for Learning and Teaching

These outcomes should be addressed at various times throughout this entire unit. They provide an interesting and relevant context to enhance the learning environment.

Students should use principles of energy and momentum to describe and explain the operation and improvement of various technological items. The items should include a range from the most inelastic ones (such as steel toes in boots, crumple zones in cars, and other safety equipment) to those behaving in a most elastic way (such as baseball bats or dent-resistant polymer panels used in some car doors and fenders).

Students should be able to apply the principles of dynamics to the investigation of real-world problems. One context for such an investigation would be the technology of running shoes. Students should investigate the elastic nature of various component parts of running shoe soles by cutting cross sections and separating the layers. Then, by dropping ball bearings on each layer and measuring the rebound height, they could compare how various layers and materials behave, and discuss whether they absorb (inelastic) or return (elastic) energy. Students might use the differences in the sizes of tennis racquets that enlarge the "sweet spot" as another example. By dropping a new tennis ball in various locations on a rigidly mounted racquet and measuring the rebound height, students can analyse a variety of variables, such as head area, tension, and string material.

Students could bring in various samples of protective headgear, such as construction hard hats, bicycle helmets, football helmets, and motorcycle helmets. Their design and operation could be analysed based on principles of energy conservation and transformation and momentum conservation and transfer. Students should determine criteria by which these devices can then be evaluated. Students could record in their logs the data from tests they conduct, come to tentative conclusions, and report results to the class.

Students should analyse an example of a technological solution based on an understanding of energy concepts. Typical examples include the development of airbags for motor vehicles, and ABS braking systems. Students could also investigate design changes made in launch vehicles (like rockets) since the advent of the space program, and the relationship to payload.

Students should be able to demonstrate the use of appropriate language and conventions. The importance of "knowing your audience" should be stressed.

Technological Implications

Tasks for Instruction and/or Assessment

Performance

- Research the application of technology in a specific sport, then debate how to enhance performance by modifying the equipment. Apply relevant physics concepts in your debate. An example might be as follows:
  - Be it resolved that aluminium baseball bats should be permitted in professional baseball. (115-5, 116-4, 116-6, 114-9)

Presentation

- The Parent Teacher Organization (PTO) of your local elementary school has asked your team of three members to participate in a safety assessment of their playground. Select one piece of playground apparatus. Do a momentum and energy analysis and make recommendations as to what modifications should be made to the apparatus. As a consultants' group, you must prepare an audio-visual presentation to the PTO. (114-9, 116-6, 115-5, 116-4)

Paper and Pencil

- Write a report on your selected technological example. Your report should clearly demonstrate the development of a technological solution based on *existing* scientific knowledge. Be sure to clarify the relationship of technology to science. (116-4)

Journal

- While technological solutions may generate new science, such as in the development of Teflon™ in the space program, airbags are a case in which technology utilized existing scientific knowledge. Explain this. (116-4)

Resources/Notes

MHR *Physics,* pp. 323-326

Work, Power, and Efficiency
~8 Classes

Outcomes

Students will be expected to

- **analyse quantitatively the relationships among force, displacement, and work** (325-9)

- **analyse common energy transformation situations using the closed system work-energy theorem** (326-7)
  - relate energy transformations to work done
  - analyse kinetic energy transformations related to the closed system work-energy theorem

Elaborations—Strategies for Learning and Teaching

The outcomes (114-9, 115-5,116-4, 116-6) on p. 51 should be addressed at various times throughout this entire unit. They provide an interesting, and relevant context to enhance the learning environment.

Prior to quantitative analysis, students must understand that work done on an object is the product of the force applied and the displacement of the object in the direction of the applied force. Although the unit of work is the joule (unit of energy), students should understand that work is not energy, but rather a quantity that describes a transfer of energy. To further student understanding of work, teachers should provide them with various opportunities to investigate situations where force and/or motion are present but no work is done.

Students should be able to determine the work done on an object by determining the area under a related force vs. position graph.

Quantitative analysis of work involving forces applied at an angle is beyond the scope of Physics 521A and will be formally addressed in Physics 621A.

In any closed system, work done is equal to change in the energy. This equivalence is known as the work-energy theorem.

Students should see the algebraic genesis of the concepts from a cause/effect perspective. Teachers could talk about the concepts by using the following information. "Work" is the name given to the product of force and displacement. Since more work is done if a larger force acts, or if the same force acts through a larger distance, the $F\Delta d$ product is a "cause." What is the "effect"? From kinematics, rearranging:

$$\vec{v}_f^{\,2} = \vec{v}_i^{\,2} + 2\vec{a}\Delta\vec{d}$$

$$2\vec{a}\Delta\vec{d} = \vec{v}_f^{\,2} - \vec{v}_i^{\,2}$$

but F = ma, so $\vec{a} = \frac{\vec{F}}{m}$, substitute into above

resulting in the following: $\vec{F}\Delta\vec{d} = \frac{1}{2}(m\vec{v}_f^{\,2} - m\vec{v}_i^{\,2})$.

$F\Delta d$ is work, but what is on the right side? This changes an initial value at v_1 to a final value at v_2. This "$mv^2/2$" represents kinetic energy, which has a different value at each velocity. Students need convincing that "$mv^2/2$" can be represented by E, or K.E., or E_K or any other symbol, and that this is no different from saying mass can be represented by m. Energy is a quantity with a compound unit, but it is still a single quantity.

Work, Power, and Efficiency
~8 Classes

Tasks for Instruction and/or Assessment

Paper and Pencil

- A 25 kg dumbbell is lifted to a height of 0.60 m. How much work was done on the dumbbell when it was raised? When it was lowered? Identify the forces doing the work in each case. (325-9)
- A 1400 kg truck travelling at +55 km/h is brought to rest. How much work was done by friction? If the braking distance was +15m, what was the average frictional force? (326-7)
- An average force of 8.0 N is applied to a 1.2 kg dynamics cart that is initially at rest. If the force is maintained for a displacement of +0.80 m, what velocity will the cart attain? If the force is maintained over a displacement of 1.6 m, what velocity is reached? What is the ratio of the two velocities? Explain in terms of work and energy why this is so. Compared to the first trial, what could you change to give the cart twice the speed? (326-7)
- A locomotive exerts a constant forward force of 5.4×10^4 N while pulling a train at a constant velocity of +25 m/s for 1.0 h. How much work does the locomotive do? What average power did the locomotive generate while pulling the train? (325-9, 325-10)

Performance

- Perform an experiment to analyse the work-kinetic energy theorem. A low friction dynamics cart could be pulled across a horizontal surface where force and corresponding position data can be collected and analysed. (325-9, 326-7)

Resources/Notes

MHR *Physics*, pp. 216-228
pp. 233-235

MHR *Physics*, pp. 236-246

Work, Power, and Efficiency *continued...*
~8 Classes

Outcomes

Students will be expected to

- **analyse common energy transformation situations using the closed system work-energy theorem (326-7) *continued...***
  - relate energy transformations to work done
  - define gravitational potential (Eg)
  - analyse potential energy transformations (gravitational) related to the closed system work-energy theorem
- **analyse quantitatively the relationships among work, time, and power (325-10)**
- **determine the percent efficiency of energy transformation (326-8)**

Elaborations—Strategies for Learning and Teaching

Students are expected to analyse work-energy transformations as they pertain to gravitational potential energy ($W = m\vec{g}\Delta h$).

Please note: Energy transformations involving elastic potential energy and related topics (Hooke' Law) are not addressed in this curriculum.

Students should also be shown the algebraic genesis of the concepts from a cause/effect perspective providing students with an in-context algebraic derivation of the work-gravitational potential energy formula.

Dimensionally, work is N•m. Energy is $kg{\cdot}m^2/s^2$.

$$N{\cdot}m = kg{\cdot}m/s^2 \cdot m = kg{\cdot}m^2/s^2$$

For convenience, both are called "joules," which is the unit for all forms of energy.

For an introductory activity, students could be asked to design and carry out an investigation in which they measure force, displacement, and time, and calculate work, power, and efficiency. Situations to examine could include lifting a dynamics cart 1.0 m, pushing the dynamics cart 1.0 m horizontally, and pushing it up a ramp to a height of 1.0 m. The students should be asked to calculate the efficiency of the ramp (the ratio of $W_{rolling}:W_{lifting}$).

Work, Power, and Efficiency *continued...*

~8 Classes

Tasks for Instruction and/or Assessment

Paper and Pencil

- A 25.0 kg box is placed on a shelf 2.0 m above the floor. How much work was done on the box? What is the change in the box's gravitational potential energy? If it took 0.90 s to raise the box, what power was used? (325-10, 326.7)
- As a written record of the dynamics cart exploration, submit work sheets that include neat sketches, data, and calculations for each of the three situations from your lab activity. (325-10, 326-8)

Informal Observation

- While trials involving the dynamics carts are being conducted, individual student participation can be monitored. (325-7, 325-10)

Journal

- Referring to the data collected, describe how force, displacement, work, time, and power are related. Give an analysis with an explanation of your understanding of the situation. (325-9, 325-10)

Presentation

- Based on your investigations of transformation situations, develop a poster or other visual display that illustrates the work-energy theorem. (326-7)
- What is meant by each of the following? (326-7)

$$W = \Delta E$$
$$E_k = \frac{mv^2}{2}$$
$$E_g = mgh$$

Resources/Notes

MHR *Physics*, pp. 247-254

Omit: Elastic Potential Energy and Hooke's Law pp. 254-261

MHR *Physics*, pp. 262-271

Work, Power, and Efficiency *continued...*

~8 Classes

Outcomes

Students will be expected to

- **design an experiment identifying and controlling major variables (212-3)**
- **carry out procedures, controlling the major variables and adapting or extending procedures where required (213-2)**
- **use instruments effectively and accurately for collecting data (213-3)**
- **compare theoretical and empirical values and account for discrepancies (214-7)**

Elaborations—Strategies for Learning and Teaching

Outcomes 212-3, 213-2, 213-3, 214-7 can be addressed by performing an investigation involving pulley systems, work, and efficiency (W_{input} :W_{output}). Please note: mechanical advantage and ideal mechanical advantage are not the focuses of this investigation. A discussion regarding how equivalent work can be performed to "ease the load," by inversely altering the amount of force applied and distance through which the force is applied, would serve the students well as a prelude to this investigation. The class could design the trials from classroom discussions, and student groups could conduct trials on several pulley systems simultaneously.

Individual student groups can set up the apparatus with varying supporting strands. Students can then experimentally determine the work done on the simple machine by measuring the effort displacement (meter stick) and effort force (force sensor). Similarly, the work done by the simple machine can be determined by the displacement of the load and the load force. With these variables, the efficiency of the machine can be determined.

Time permitting, students could be asked to investigate the effect of supporting strands on efficiency. From their trials they should be able to distinguish between efficiency and the ability of a simple machine to ease the load.

Work, Power, and Efficiency *continued...*

~8 Classes

Tasks for Instruction and/or Assessment

Performance

- Design an experiment to determine the efficiency of a pulley system. Decide on an experimental procedure by identifying and controlling major variables. (212-3, 213-2, 213-3, 214-7)

Presentation

- In groups of three to four, demonstrate and discuss your experiment on pulley systems. Decide on your presentation format. An explanation of your data, procedure, and the efficiency of your machine should be included. (212-3, 213-2, 213-3, 214-7)

Resources/Notes

Transformation, Total Energy, and Conservation
~8 Classes

Outcomes

Students will be expected to

- **describe quantitatively mechanical energy as the sum of kinetic and potential energies (326-5)**
  - distinguish between conservative and non-conservative forces
  - solve problems using the law of conservation of mechanical energy involving:
    - gravitational potential / kinetic
    - elastic potential / kinetic
    - all three forms of mechanical energy combined

- **analyse quantitatively problems related to kinematics and dynamics using the mechanical energy concept (326-6)**

Elaborations—Strategies for Learning and Teaching

Student should be aware that the total mechanical energy (kinetic, gravitational potential, elastic potential) of a system is conserved when during an energy transformation the work is done through conservative forces only ($E_k + E_p + E_e = E_k' + E_p' + E_e'$). Please note that students are expected to know that elastic potential energy exist as a component of mechanical energy; however, students are not expected to perform calculations of elastic potential energy.

To save time, teachers may wish to immediately discuss conservative and non-conservative force and have students move directly into the concepts related to conservation of total energy (SCO 326-1; Section 7.2). Teaching conservation of mechanical energy as an intermediary to total energy, as an isolated topic, may not be necessary.

Students have developed confidence in kinematics tools for solving motion problems in a straight line. In achieving this outcome, students should come to appreciate energy solutions for vertical motions whether in a straight line or not, and even for relatively complex motions such as oscillations, in which net acceleration is constantly changing.

A good initial problem would be to complete the following table for a 2.0 kg mass dropped from a height of 1.0 m.

Energies of a Falling Mass

h (m)	t (s)	v (m/s)	E_k (j)	E_g (j)
1.0				
0.8				
0.5				
0.3				
0				

Could you determine the velocity at 0.4 m using energy concepts only?

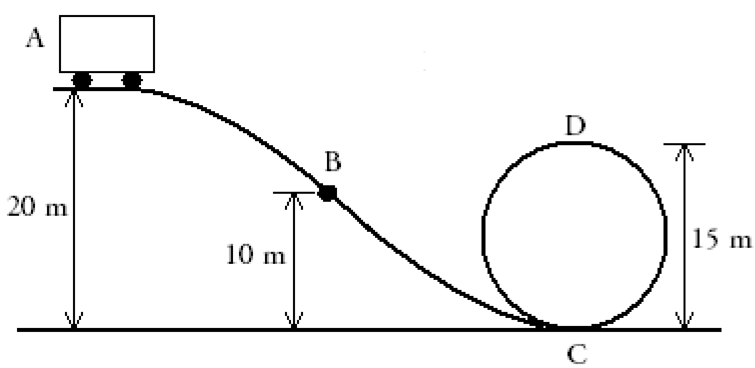
Transformation, Total Energy, and Conservation
~8 Classes

Tasks for Instruction and/or Assessment

Paper and Pencil

Unless otherwise stated, assume all work is done through conservative forces.

- Kristen is playing on a swing. At her highest swing, the seat is 3.2 m above the rest position. What speed does she have as she passes through the lowest position? (326-5, 326-6)
- A pole vaulter wants to clear the bar at a height of 7.0 m above the mat. What horizontal speed must he/she have to just clear the bar? What role does the pole play in the pole vault? (326-5, 326-6)
- When analysing a problem, how do you decide whether to use kinematics, momentum, or energy concepts to solve for unknowns? (326-6)
- After referring to the diagram below, answer the following questions:
  - How much gravitational potential energy does the roller coaster car have at position A if the loaded mass is 1100 kg?
  - What is the maximum kinetic energy the car could have at B?
  - What speed would it have at B?
  - What speed would the car have at position D? (326-5)



- A "superball" is dropped from a height of 1.5 m onto a hard floor and bounces back up to virtually the same height. Describe completely the energy changes undergone by the ball from the time it is released until the time it reaches maximum rebound height. In particular, account for the changes that occur while the ball is in contact with the floor. (326-5)

Resources/Notes

MHR *Physics,* pp. 278-289

Omit: Elastic Potential Energy pp. 290-299

Transformation, Total Energy, and Conservation *continued...*
~8 Classes

Outcomes

Students will be expected to

- **analyse quantitatively the relationships among mass, height, speed, and heat energy using the law of conservation of energy (326-1)**
  - define system, isolated system, closed system
  - using the law of conservation of energy, solve problems that include changes in gravitational potential energy and kinetic energy
  - explain the role of friction and the loss of mechanical energy from a system
- **analyse quantitatively problems related to kinematics and dynamics using the mechanical energy concept (326-6)**

Elaborations—Strategies for Learning and Teaching

Previous outcomes addressed conservation of mechanical energy where only conservative forces were considered during the energy transformation. During work on these outcomes, students should

- discuss ways in which energy leaves a system, such as sound and heat that resulted from non-conservative forces (frictional forces);
- solve problems using the law of conservation of total energy including changes in gravitational potential energy, kinetic energy, and energy resulting from non-conservative forces;
- explain the effect of work done by non-conservative forces (friction) resulting in the loss of mechanical energy from a system;
- explain the effect of work done by non-conservative forces resulting in an increase in mechanical energy of a system.

With regard to the scope of outcome 326-1, when performing quantitative analysis, students should be provided with, or asked for, the energy value that resulted from non-conservative force. Students are not expected to further analyse the non-conservative energy values to determine the magnitude of the related force, or vice-versa. Similarly, the energy value for elastic potential can be asked for, or provided; however, students are not expected to calculate from components quantities the value of elactic potential energy.

When one is addressing a problem for analysis, algebra should always be modelled consistently and in context. Some students follow the logic of algebraic deduction intuitively. Those who do not may need explanatory detail. Every substitution or rearrangement might be a potential roadblock. Even so, all students need experience with deductive reasoning of this type.

There are a variety of ways to write the law of conservation of energy. If we define the work done by non-conservative forces (W_{nc}) as the difference between initial and final mechanical energy, where

$$W_{nc} = E_{final} - E_{initial} \quad ,$$

then a rearrangement of this formula with all energy terms included would be written as folows:

$$W_{nc} + E_p + E_k + E_e = E_p' + E_k' + E_e' \quad .$$

In the above formula, W_{nc} is negative if energy is lost from the system, and positive if energy is gained by the system.

Transformation, Total Energy, and Conservation *continued...*
~8 Classes

Tasks for Instruction and/or Assessment

Performance

- Design and conduct an experiment to demonstrate an energy transformation, and account for discrepancies. For example, you could release a block at the top of a ramp and, using available technology, determine the velocity at several points, including the bottom. Alternatively, using Hot Wheels™ tracks and cars, you could construct a mini roller coaster. A car could be released at the top of an incline and allowed to go up a second slope. The height of the second "hill" could be adjusted until the car can no longer reach the top with v=0. The transfer of energy from gravitational potential to kinetic and back to potential could be studied, taking into account energy transferred to heat through friction. You could compare theoretical kinetic energy values to the actual values and account for any differences. (326-1, 326-5, 214-7, 326-6)
- Create a problem that involves all forms of mechanical energy and includes a non-conservative energy value. Have your classmates solve for the unknown and explain their thought process in finding the solution. (326-1, 326-5, 214-7, 326-6)

Presentation

- Working in groups of two to four, prepare a report for the makers of Hot Wheels™. Offer the results of your investigation(s) and make recommendations for modifications to the toy. Present your report to the class. (116-6, 326-1)
- Present to your class a song, poem, speech, or short story that involves the following terms: work, kinetic energy, gravitational potential energy, elastic potential energy, and efficiency. Your presentation should show a clear understanding of the relationships among the terms. (326-1, 326-6, 326-7, 326-8)

Resources/Notes

MHR *Physics*, pp. 301-309

Transformation, Total Energy, and Conservation *continued...*
~8 Classes

Outcomes

Students will be expected to

- **design an experiment, select and use appropriate tools, carry out procedures, compile and organize data, and interpret patterns in the data to answer a question regarding the conservation of energy**
(212-3, 212-8, 213-2, 214-3, 214-5, 214-11)

- **distinguish between problems that can be solved by the application of physics-related technologies and those that cannot** (118-8)

Elaborations—Strategies for Learning and Teaching

Students should investigate the energy transformation (kinetic - gravitational potential) involved in a cart that travels up an incline and returns to its original position. Using a motion sensor to collect data, students can create a graph of gravitational potential energy vs. time and kinetic energy vs. time. These graphs can be analysed and compared. Students can compare the highest value for gravitational potential energy from the gravitational potential energy vs. time graph to the final kinetic energy, and acount for discrepencies. They could also be asked to predict the shape of the total mechanical energy vs. time graph prior to creating it.

As a culminating task, the gravitational potential energy, kinetic energy, and total mechanical energy graphs can be superimposed. Students should attempt to provide a comprehensive description of the data that they are viewing. Using the law of conservation of energy, the students can calculate the energy loss in the system as a result of non-conservative forces.

One possible context that students should recognize is that injury prevention in passenger cars is possible with technological solutions, whereas the goal of eliminating car accidents involves human behaviour that cannot be technologically controlled. Convenient, comfortable seat belts have had a positive impact on belt usage. When studying broad issues like highway safety, students should learn to analyse the problem, categorizing those elements that technology can address and those that can be addressed only by people.

Transformation, Total Energy, and Conservation *continued...*

~8 Classes

Tasks for Instruction and/or Assessment

Informal Observation

- Using a rubric, the teacher can observe students as they conduct the investigation selected for this outcome. (212-3, 213-4, 214-16)
- While groups present their debates about physics-related technologies, and the class discusses the situations (see presentation below), the teacher may apply a rubric for assessment. (118-8)

Performance

- Conduct an experiment on transformation, total energy, and conservation, and write a lab report on your experiment. Include your collected data, analysis, information, conclusion(s), and a graph. (212-3, 212-8, 213-2, 214-3, 214-5, 214-11)

Paper and Pencil

- Write a scientific abstract about your experiment design, results, and interpretations. (212-3, 212-8, 213-2, 214-3, 214-5, 214-11)
- Write a letter to an editor presenting the scientific elements and the social implications surrounding a relevant issue (e.g., use of airbags, bicycle helmets, seat-belts). (118-8)

Presentation

- In groups, debate a problem. Can it be solved by the application of physics-related technologies or not? Some examples include the following:
  - Be it resolved that all major highways in the Atlantic region be twinned.
  - Be it resolved that helmets must be worn by skateboarders. (118-8)

Resources/Notes

Conservation of Momentum
~3 Classes

Outcomes

Students will be expected to

- **determine which laws of conservation, momentum, and energy are best used to analyse and solve particular real-life problems in elastic and inelastic interactions (326-4)**
  - differentiate between elastic and inelastic situations
- **apply quantitatively the laws of conservation of momentum to one-dimensional collisions and explosions (326-3)**

Elaborations—Strategies for Learning and Teaching

Students should be challenged to decide which conservation law is most useful in explaining the operation of systems of two or more objects. Students should analyse various items (e.g., a golf club, a tennis racquet, a pile driver, a jackhammer). Teachers can facilitate discussions with questions such as the following:

- What is "wrong" with an under-inflated basketball?
- Would an "ideal" system be 100% elastic?
- In which situations is an elastic collision preferable?
- Are there situations where a 100% elastic collision is not desirable?

Using dynamics carts, students should carry out trials and collect and interpret data. They should be challenged to predict, observe, and explain what would happen in specific situations with the carts. They should be able to interpret the final conditions of some collisions and explosions, and describe the initial conditions. Teachers could facilitate student analysis by asking questions such as, What evidence do you have to support your statement?

The following situations could be set up:

- moving cart A hits stationary identical cart B, and sticks
- moving cart A hits stationary heavier cart B, and sticks
- moving cart A hits stationary identical cart B, and they separate
- moving cart A hits stationary heavier cart B, and they separate
- moving heavier cart A hits stationary cart B, and they separate
- moving cart A hits identical cart B moving head on at the same speed

Where possible, masses should be kept to simple multiples so that patterns in the data are more apparent. One or more motion sensors could be used to collect and analyse data. If an air track or table is available, it could be used to determine values more precisely, but some investigation with dynamics carts gives students a more realistic experience.

It might be possible to arrange for a police crash investigator to be a guest speaker. He/she could provide a realistic context for this study.

Students might get a better grasp of momentum conservation if they simulate a variety of situations in slow motion.

For an optional extension, students could determine both final velocities for one-dimensional collisions by the method of simultaneous equations.

Conservation of Momentum
~3 Classes

Tasks for Instruction and/or Assessment

Performance

- Conduct a collision analysis experiment. (326-3, 326-4)

Journal

- Write down your observations and questions regarding the use of dynamics carts. Organize them. How does writing your observations help your understanding of your collision experiment? (326-3)
- One billiard ball collides with a stationary ball. The first ball stops while the second moves away with the same velocity as the original ball. Explain what happens in this interaction, using the concepts of momentum and energy. (326-3, 326-4)
- Write a note explaining momentum, energy, and their transformations so a grade 8 student could understand them. (326-3, 326-4)

Paper and Pencil

- A golf ball of mass 50.0 g is hit by a golf club at a speed of 35 m/s. If the effective mass of the club head is 0.32 kg and the collision is totally elastic, what velocity will the ball have just after the impact? (326-3, 326-4)
- Write a report of your collision analysis lab. You are expected to look for patterns in your raw data. For example, you can investigate how Δv is related to mass ratio. Account for the difference in total momentum from trial to trial. You should describe, in detail, the nature of the interaction during a collision as a plunger compresses and rebounds and relate this observation to other interactions, such as with billiard balls and/or automobiles. Some discussion of error (less than 100% conservation of momentum) is expected. (326-3, 326-4)
- A 2.4 kg dynamics cart moving at 1.5 m/s undergoes an in-line elastic collision with another stationary cart of the same mass. What will the velocity of the stationary cart be after impact? (326-3, 326-4)
- A 65 kg boy runs at a constant speed of 6.0 m/s. He jumps on a stationary 35 kg freight dolly so that his feet stay in one position and the combined mass (boy + dolly) moves off at a new speed. Assume that the dolly wheels are frictionless. (326-4, 326-3)
  - What final velocity will the combined mass have?
  - What impulse acted on the dolly? On the boy?
  - Was energy conserved in this interaction?
  - If the best estimate of the time of interaction is 0.20 seconds, what force acted on the dolly?
  - What acceleration did the boy experience?

Resources/Notes

MHR *Physics,* pp. 310-322

Waves *(~22 Classes)*

Introduction

Everyone has seen waves in many forms, such as water waves hitting a beach, standing waves in telephone lines, and travelling waves in a skipping rope. Students should observe, predict, and explain specific wave behaviors, such as reflection, refraction, diffraction, and interference. Students could begin their study of waves with familiar mechanical waves, extend their study to sound waves, and then use wave principles that they have developed to explain and predict the behavior of light and other electromagnetic waves. Students should be encouraged to develop their vocabulary and working definitions of wave terminology from their own experiences and from directed activities in class. Through various investigations, they should recognize that any periodic disturbance creates a wave, and that the disturbance transmits energy (and therefore information) from one place to another. Familiar activities with Slinkies™ and ripple tanks would allow students to observe, predict, and explain specific wave behaviors, such as reflection, refraction, diffraction, and interference.

Focus and Context

Problem-solving activities should be linked with STSE connections in various activities. Examples could include resonance and earthquakes, or the quest for energy. For example, in considering offshore exploration for oil and gas, students must assess risk and benefit.

Because the study of waves is so broad, students have many opportunities to research and investigate different topics—musical instruments, optics, communications systems, electronics, medical imaging, non-destructive testing, and sound pollution, to suggest just a few. As they move from phenomena that can be observed directly, such as mechanical and water waves, to those less directly observable, such as sound and EM waves, students should be challenged to make inferences based on wave phenomena. They should increasingly recognize the power of physics in general, and wave concepts in particular, to convey information and permit exploration where the unaided human senses fail. The range of tools used to make indirect observations is vast—from simple hand lenses, to compound microscopes, to scanning electron microscopes; from radio telescopes to MRI, CAT, and PET scanning technology. However, in all scientific and technological endeavours, the tools to extend our senses were developed using the concepts and principles of physics.

Science Curriculum Links

In grade 8, students studied optics in relation to their scientific properties, to their use in technological devices, and their relationship to society. Physics 621A continues wave theory with the relationship between potential and kinetic energies of a mass in simple harmonic motion and the properties of electromagnetic radiation and sound.

Curriculum Outcomes

STSE

Students will be expected to

Nature of Science and Technology

115-5 analyse why and how a particular technology was developed and improved over time

Relationships between Science and Technology

116-2 analyse and describe examples where scientific understanding was enhanced or revised as a result of the invention of a technology

116-7 analyse natural and technological systems to interpret and explain their structure and dynamics

Social and Environmental Contexts of Science and Technology

117-2 analyse society's influence on scientific and technological endeavours

118-2 analyse from a variety of perspectives the risks and benefits to society and the environment of applying scientific knowledge or introducing a particular technology

Skills

Students will be expected to

Initiating and Planning

212-4 state a prediction and a hypothesis based on available evidence and background information

212-7 formulate operational definitions of major variables

Performing and Recording

213-1 implement appropriate sampling procedures

213-7 select and integrate information from various print and electronic sources or from several parts of the same source

Analysing and Interpreting

214-8 evaluate the relevance, reliability, and adequacy of data and data collection methods

Knowledge

Students will be expected to

327-1 describe the characteristics of longitudinal and transverse waves

327-2 apply the wave equation to explain and predict the behaviour of waves

327-7 apply the laws of reflection and the laws of refraction to predict wave behaviour

327-8 explain qualitatively and quantitatively the phenomena of wave interference, diffraction, reflection, and refraction, and the Doppler-Fizeau effect

327-5 compare and describe the properties of electromagnetic radiation and sound

327-6 describe how sound and electromagnetic radiation, as forms of energy, are produced and transmitted

Fundamental Properties
~6 Classes

Outcomes

Students will be expected to

- **formulate operational definitions of major variables** (212-7)

Elaborations—Strategies for Learning and Teaching

From seeing ocean waves, to making ripples in a puddle, to playing with a Slinky™, all students have viewed and/or experienced basic wave motion. In order to further analyse wave motion as a formal topic in physics, students should be provided with the opportunity to formulate operational definitions of the fundamental quantities related to transverse mechanical waves. In completing this outcome, through discussions and demonstrations, students should be able to describe periodic motion, rest position, amplitude, period, frequency, wavelength, speed, phase, natural frequency, and resonance.

- **describe the production, characteristics, and behaviours of longitudinal and transverse mechanical waves** (327-1)

Disturbances in a medium create pulses and waves, and these transfer energy. The students should use their understanding of energy and its analysis in systems to examine how waves are produced. They should relate the appearance of a wave to the energy input and be able to describe how energy is transmitted by a wave. Through a variety of experiences with waves on springs and in ripple tanks, students should develop operational definitions that might be refined or expanded as their study of waves continues. To begin, large, slow pulses should be observed using long helical springs and Slinkies™.

- **apply the wave equation to explain and predict the behaviour of waves** (327-2)

Students should be able to qualitatively and quantitatively describe the relationships among period, frequency, wavelength, and velocity. They should solve problems involving these quantities using the universal wave equation

$$\mathbf{v} = \mathbf{f}\lambda \quad \left(\textbf{note}\text{: } f = \frac{1}{T}\right)$$

Opportunities exist to connect to prior student knowledge of kinematics by deriving the universal wave equation using the following kinematics equation as a starting point:

$$\vec{v} = \frac{\Delta\vec{d}}{\Delta\vec{t}} \quad .$$

In the event that a wave hits a boundary, students should be able to describe the characteristics (phase, speed, frequency, wavelength) of the reflected and transmitted wave in relation to the incident wave.

Fundamental Properties
~6 Classes

Tasks for Instruction and/or Assessment

Informal Observation

- Observe students demonstrating and making measurements of the characteristics of waves and experimentally verify the universal wave equation. (327-1, 327-2, 212-7, 213-1, 214-8)

Performance

- Demonstrate using a Slinky™ and diagrams of two waves in phase and two waves out of phase. (327-1, 212-7)

Paper and Pencil

- Distinguish between the period and frequency of a wave. (327-1, 212-7)
- Which property of a wave is a measure of the energy in the wave? Use the work-energy theorem to explain your answer. (327-1, 212-7)
- An oscillator vibrates the end of a spring at a frequency of 10.0 Hz. The distance between adjacent crests in the wave pattern formed is 1.50 m. What is the speed of the wave? (327-2)
- How is a longitudinal wave different from a transverse wave? Give a common example of each. (327-1)
- Two waves are created from opposite ends of a 10.0 m long spring. The wave from end A has an amplitude of 50.0 cm to the left of the relaxed position and a frequency of 5.00 Hz. The wave from end B has an amplitude of 30.0 cm on the opposite side of the spring and a frequency of 10.0 Hz.
  - Can you predict at what point on the spring the two pulses meet? (327-1, 327-2)

Resources/Notes

MHR *Physics,* pp. 335-343

MHR *Physics,* pp. 344-353

MHR *Physics,* pp. 346-353

Fundamental Properties *continued...*

~6 Classes

Outcomes

Students will be expected to

- **explain qualitatively and quantitatively the phenomena of wave interference, diffraction, reflection, and refraction, and the Doppler-Fizeau effect (327-8)**
  - explain the principle of superposition
  - explain how standing waves are formed

Elaborations—Strategies for Learning and Teaching

Students should be expected to describe the principle of superposition. Slinkies™ are ideal for observing incident waves prior to, and resultant wave during, interference. Several computer animations are available online which provide students with an opportunity to observe the dynamic interaction of the incident waves during interference.

Students should be expected to extend their knowledge of the principle of superposition to explain the stationary nodes and antinodes during the production of standing waves. Students should become familiar with natural frequency, fundamental frequency, and overtones.

- **select and integrate information from various print and electronic sources (213-7)**
- **analyse why and how a particular technology was developed and improved over time (115-5)**
- **analyse from a variety of perspectives the risks and benefits to society and to the environment when applying scientific knowledge or introducing a particular technology (118-2)**
- **analyse natural and technological systems to interpret their structure and dynamics (116-7)**
- **analyse society's influence on scientific and technological endeavours (117-2)**

Students should research the application of the wave to a specific technology, such as supersonic aircraft. They could identify problems related to wave theory that have kept the technology from becoming more commonplace. The medical applications of ultrasound, the principle and uses of fibre optics, and the Tacoma Narrows bridge make excellent topics. Students should focus their research on energy efficiency, cost effectiveness, product safety, potential health hazards, and other criteria that they might suggest.

There have been several attempts (particularly in Great Britain) to develop technologies to gain energy from wave motion. At least one Canadian attempt has been made. Students should investigate why and how wave energy has been harnessed in the past and what possibilities exist for the near future. A time line might be helpful to chart the development of the technology.

Fundamental Properties *continued...*
~6 Classes

Tasks for Instruction and/or Assessment

Performance

- Sketch examples of constructive and destructive interference. (327-8)
- Research the design and construction of the Confederation Bridge between New Brunswick and Prince Edward Island. Develop a set of questions for further investigation, such as the following:
  - What unique component designs and construction techniques were involved in the project?
  - What wave phenomena were anticipated by the designers?
  - How does the bridge meet these criteria?
  - What competing social pressures had to be considered by the planners?
- Describe and analyse society's influence on the natural and/or technological example that you have researched. (115-5, 116-7, 117-2, 118-2, 213-7)

Paper and Pencil

- Two waves pulses are created from opposite ends of a long spring. The wave from end A has an amplitude of 50.0 cm to the left of the relaxed position. The wave from end B has an amplitude of 30.0 cm on the opposite side of the spring.
  - What will the spring look like when the pulses meet? Draw a sketch. (327-1, 327-8)
- Explain how standing waves are formed. (327-8)
- Prepare a written report about the wave-related technology you researched. (115-5, 116-7, 117-2, 118-2, 213-7)
- Simulate the writing of a weekend newspaper feature article, with one student in each group acting as features editor. Set deadlines for research, draft copies, and final version. Responsibilities should be divided. Publish this article in your school's newspaper. Suggestions may include the following:
  - resonance in bridges or buildings
  - impact of sound in your daily life
  - musical instruments such as brass and wind
  - sonar in ships
  - fibre optics (115-5, 116-7, 117-2, 118-2, 213-7)
- Create a "Help Wanted" notice advertising for a person to work in a wave-related employment field. Your notice will be part of a classroom bulletin board display. (115-5, 116-7, 117-2, 118-2, 213-7)

Presentation

- Perform a presentation, using PowerPoint or similar technology, on the technology you researched. Use visuals effectively in your presentation. (115-5, 116-7, 117-2, 118-2, 213-7)

Resources/Notes

MHR *Physics,* pp. 354-362

MHR *Physics,* pp. 368, 411-414

Fundamental Properties *continued...*

~6 Classes

Outcomes

Students will be expected to

- **implement appropriate sampling procedures in wave experiments (213-1)**
- **evaluate the relevance, reliability, and adequacy of data and data collection methods in wave experiments (214-8)**

Elaborations—Strategies for Learning and Teaching

Using a Slinky™, students should create a standing wave. They should collect data to enable them to calculate speed. The frequency can be determined by counting and timing a number of oscillations; the wavelength can be determined by direct measurement (the distance between crests is half the wavelength); and the speed can be calculated. By creating different standing patterns and repeating measurements, students can verify that the wave speed in the medium is constant. The teacher might wish to do this as a demonstration with half the class at a time. Several tables placed end to end could be used to do trials with a Slinky™. Similarly, trials could be performed on the classroom floor.

- **apply the laws of reflection and the laws of refraction to predict wave behaviour (327-7)**
- **hypothesize about wave behaviour, using available evidence and background information (212-4)**

Based on their experiences, students should be asked to predict and draw sketches to represent what reflection, refraction, and standing waves would look like in a ripple tank. It is expected that appropriate terminology be used in their explanations (e.g., normal line, angle of incidence, angle of reflection, wavefront, ray, nodal line, antinodal line, node, antinode). Students might work in groups, with each group adopting a different perspective on waves. They could report their findings to the class. Similarly, students should be asked to predict how destructive resonance causes large structure damage during an earthquake.

Student investigations of waves in a ripple tank will form the foundation for further study of interference of longitudinal and electromagnetic radiation.

Fundamental Properties *continued...*
~6 Classes

Tasks for Instruction and/or Assessment

Performance

- Perform an experiment to investigate the fundamental properties of transverse waves and the universal wave equation. (212-7, 213-1, 214-8, 327-1, 327-2, 327-8)
- Investigate interference of single wave pulses and the formation of standing waves. (212-7, 213-1, 214-8, 327-1, 327-2, 327-8)

Paper and Pencil

- Record observations, both sketches and data, and draw conclusions from a wave activity that you have completed. (212-7, 213-1, 214-8, 327-1, 327-2, 327-8)

Presentation

- Create a display that shows the relationship between a ray diagram and a wavefront diagram for a specific situation, such as circular reflections from a straight barrier. (327-8, 327-7)

Resources/Notes

MHR *Physics,* pp. 359-360

MHR *Physics,* pp. 363-370

Sound Waves and Electromagnetic Radiation
~16 Classes

Outcomes

Students will be expected to

- **compare and describe the properties of electromagnetic radiation and sound** (327-5)

- **describe how sound and electromagnetic radiation, as forms of energy, are produced and transmitted** (327-6)
  – describe how sound is produced, giving an example in nature and technology
  – describe how sound and electromagnetic radiation are transmitted
  – list the factors upon which the speed of sound depends
  – perform basic calculations involving the speed of sound and light

Elaborations—Strategies for Learning and Teaching

This section provides students with the opportunity to extend their knowledge of the fundamental properties developed using transverse waves by examining both longitudinal waves and electromagnetic radiation.

A comparison of sound and electromagnetic radiation should begin with a discussion of the medium through which these waves can travel. In order to bridge student understanding of the ability of electromagnetic radiation to travel through space with no medium, it may be helpful to discuss familiar non-contact forces such as gravity and effect of a magnet on iron filings.

Students could be asked to create a concept map to compare and describe properties of these wave types. They can add to their concept map as more information is collected throughout this unit. The discussion of electromagnetic waves will be covered in more detail in Physics 621A.

Students should recognize that light is only one of many types of electromagnetic radiation. They should be able to describe, using appropriate terminology and examples, how sound is produced and transmitted. The production of magnetic fields as a result of a charge in motion is a topic addressed in Physics 621A; therefore, it is important to note that it is beyond the scope of Physics 521A to explain how oscillating electric and magnetic (electromagnetic wave) fields are caused by an accelerating charge.

After listening to a series of common sounds, students should be asked to comment on the cause and nature of the sounds. Students should explore the properties that are used to distinguish sounds. Sound perceptions such as pitch, loudness, and tone could be investigated and compared to sound wave characteristics previously addressed, such as amplitude, frequency, wave, and form. Tuning forks, sonometers, keyboards, amplifiers, oscilloscopes, probeware, and computer software could be used to investigate the frequency, wavelength, amplitude, and harmonic complexity of waveforms.

Students should list the factors that affect the speed of sound. Students should relate Mach number as the ratio of the speed of an object to the speed of sound. They should perform calculations involving speed of sound and light. It may be appropriate to address echolocation (delineation of SCO 327-8) at this point.

Sound Waves and Electromagnetic Radiation
~16 Classes

Tasks for Instruction and/or Assessment	Resources/Notes
Journal • Describe how sound is produced, giving an example of each in nature and technology. Describe how sound is transmitted. List the factors on which the speed of sound depends. (327-5, 327-6)	MHR *Physics,* various sections, pp. 374-440
Presentation • Compare and contrast properties of electromagnetic radiation and sound. (327-5, 327-6)	MHR *Physics,* pp. 374-380
Performance • Perform an investigation to determine the speed of sound. (327-6)	MHR *Physics,* pp. 385-392

Sound Waves and Electromagnetic Radiation *continued...*
~16 Classes

Outcomes

Students will be expected to

- **apply the laws of reflection and the laws of refraction to predict wave behaviour** (327-7)
- **explain qualitatively and quantitatively the phenomena of wave interference, diffraction, reflection, and refraction, and the Doppler-Fizeau effect** (327-8)
  - explain the Doppler effect and sonic booms
  - explain the phenomenon of the sonic boom, describe the problems it causes, and explain how such problems can be minimized
  - explain how sound is reflected, and the process of echolocation
  - explain the law of reflection
  - explain quantitatively and qualitatively the refraction of light, index of refraction, Snell's law, critical angle, and total internal reflection
  - explain qualitatively the refraction of sound

Elaborations—Strategies for Learning and Teaching

To develop an understanding of the Doppler effect phenomenon, students could be asked to describe the sound of an ambulance siren as it approaches their position. Typical responses might include "higher pitch," "higher frequency," and "higher volume." Students should then be asked to explain the apparent higher pitch/frequency resulting from an approaching object, and vice-versa. Discourse should proceed by describing the amplitude of the detected sound waves when an object is travelling at, or beyond, the speed of sound (sonic boom).

Wave properties such as reflection and refraction should be examined for both sound and light. During students' investigations of these outcomes, they should be encouraged to go back and forth from a ripple tank to sound and light behaviour.

Students should be able to describe the process of echolocation. By measuring the time it takes for a reflected sound to return to a source, student should be able to estimate, using the speed of sound, the distance between an object and the source.

The properties of light could be investigated in a series of group activities. Questions students might wish to address are, Do wave diagrams and ray diagrams of reflection predict similar results? and Can a virtual source be located when circular waves are reflected from a straight barrier?

Students should investigate the refraction of light and look for a relationship between incident angle and refracted angle. An investigation using a variety of liquids in semicircular plastic containers could be conducted by pairs of students to develop Snell's law and the formula: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Students should solve a variety of problems using Snell's law and water and light interference. Students should be able to identify the terminology associated with waves, such as reflected ray, refracted ray, normal, angle of incidence, angle of reflection, and angle of refraction. Students should describe and give examples of reflection, refraction, index of refraction, relative index, critical angle, and total internal reflection.

Given the index of refraction, students should draw accurate diagrams for a ray of light passing through a variety of materials.

This should be followed by the study of relative index and critical angle.

Sound Waves and Electromagnetic Radiation *continued...*

~16 Classes

Tasks for Instruction and/or Assessment

Paper and Pencil

- Submit a written report on a Snell's law investigation. (327-8, 327-7)
- Explain the phenomenon of the Doppler-Fizeau effect, and give examples. (327-8)
- Explain the phenomenon of the sonic boom. Describe the problems it causes, and explain how such problems can be minimized. (327-8)

Performance

- Given the index of refraction, draw accurate diagrams for a ray of light passing through a variety of materials. (327-8, 327-7)

Journal

- Draw a physics cartoon about a ray. Include information on incident ray, reflected ray, refracted ray, normal, angle of incidence, angle of reflection, and angle of refraction. (327-8, 327-7)

Presentation

- In groups of two to three students, create a crossword puzzle, a word search, or other puzzle activity using terms and explanations associated with waves. Include an answer sheet. Trade your puzzle(s) with another group to see if each can solve the other's puzzle. Some terms to consider include incident ray, reflected ray, refracted ray, normal, angle of incidence, angle of reflection, angle of refraction, and nodes and nodal lines. (327-8, 327-7)
- Do a multimedia presentation on waves. Describe and give examples of reflection, refraction, index of refraction, relative index, critical angle, total internal reflection, diffraction, scattering, interference, and Doppler-Fizeau effect. (327-8, 327-7)

Resources/Notes

MHR *Physics,* pp. 392-394

MHR *Physics,* pp. 395-410

MHR *Physics,* p. 407

Sound Waves and Electromagnetic Radiation *continued...*

~16 Classes

Outcomes

Students will be expected to

- **explain qualitatively and quantitatively the phenomena of wave interference, diffraction, reflection, and refraction, and the Doppler-Fizeau effect** (327-8)
- **apply the laws of reflection and the laws of refraction to predict wave behaviour** (327-7)
  - explain qualitatively and quantitatively the beat frequency resulting from the interference of two sources of slightly different frequency
  - explain qualitatively nodal and antinodal lines resulting from the interference of two sources of similar phase and frequency
  - explain how standing waves are produced from resonance in closed and open air columns
  - perform calculations involving wavelength, frequency, speed, and column length for open and closed air columns

Elaborations—Strategies for Learning and Teaching

Wave properties such as reflection and refraction should be examined for both sound and light. However, interference of light should only be examined qualitatively by making conections to water waves in a ripple tank or sound interference. It is not expected that students perform Young's experiment or calculations involving interference of light. As a prelude to studying these topics, students could be asked the question, What characteristic of sound compares to colour for light?

A simple interference pattern could be created with tuning forks creating a beat frequency. A student can calculate beat frequency by timing the beats, and can demonstrate how beat frequency is used to tune a guitar or violin.

Two loudspeakers producing the same pure tone could be used to set up a two-point source interference pattern large enough to walk through. For example, two sources producing tones of frequency 256 Hz placed 4.0 m apart will produce a good pattern. On a line parallel to the speaker plane three metres away from the sources, nodes will be spaced about 1 m apart. It is even possible to make reasonable measurements on the interference pattern and determine the wavelength of the sound source. To illustrate this, concentric circles can be drawn on two tranparencies. The transparencies can be placed (overlapped) on a projector to show the nodal and antinodal lines resulting from a two-point source interference.

Students should explain how standing waves are created from resonance in open and closed air columns. Explanation should involve appropriate terminology; therefore, students must be familiar with the music terms harmonics, fundamental, overtone, displacement node, and displacement antinode. Resonant air columns could be used to investigate the speed of sound in air. Resonance and coupling could be examined with mounted tuning forks. Resonance of specific strings could be seen in a piano or on a guitar. Students could be involved in demonstrating how instruments control sound quality by selective resonance.

Sound Waves and Electromagnetic Radiation *continued...*
~16 Classes

Tasks for Instruction and/or Assessment

Performance

- Conduct a lab to determine the speed of sound using close-tube resonance. (327-5, 327-6)
- Using a set of mounted resonance tuning forks, try to produce beat frequencies of five beats per second, and then ten beats per second. Try to duplicate this effect with small-sized pop bottles filled with water to slightly different heights. Compare you trials using a signal generator. (327-8)

Paper and Pencil

- Explain how standing waves are produced in closed and open pipes. (327-8)

Journal

- Write a short story about the life of a wave. (327-8, 327-7)
- In your journal, explain how a particular musical instrument makes use of resonance to produce its characteristic sound. (327-7, 327-8)

Resources/Notes

MHR *Physics,* pp. 415-431

MHR *Physics,* pp. 428-431

MHR *Physics,* pp. 415-427

Sound Waves and Electromagnetic Radiation *continued...*
~16 Classes

Outcomes

Students will be expected to

- **analyse and describe examples where scientific understanding was enhanced or revised as a result of the invention of a technology** (116-2)

Elaborations—Strategies for Learning and Teaching

Students should relate their understanding of resonance to situations in everyday life. The teacher could pose questions such as, How is resonance involved in the destructive force of earthquakes? Most have probably seen a car with weak shocks go over small bumps and bounce wildly. Possibly some students could videotape a wheel balancing machine in operation at a tire store and present it to the class. What examples of "good" and "bad" resonance can students identify? Students could prepare lengths of two-inch diameter PVC pipe to study open and closed tube resonance in a laboratory setting. Does light resonate in a similar way, resulting in "amplified" light?

Students could ask questions such as, What has been learned about waves through the use of ultrasound technology in medicine? Students could research how a device such as the ultrasound transponder, the microwave magnetron, or the seismograph helped scientists expand their knowledge of wave behaviour. Students should analyse an example with reference to its technology and talk about their understanding of the example.

Sound Waves and Electromagnetic Radiation *continued...*

~16 Classes

Tasks for Instruction and/or Assessment

Presentation

- Prepare presentations to report on your research. Include discussion of how technology has solved a practical problem. What influence did society's needs and interests have on the research of the device? Who has responsibility for the science used in technology? (116-2)

Resources/Notes

Appendix

Instructional Planning (Term 1)

Unit 1: Kinematics (~17 classes)			
Unit/Section Title	# Classes	Text Section/Pages	Suggested Core Investigations
Introducing Vector Quantities	~4	Section 2.2 pp. 6, 30-46	
Graphical and Algebraic Problem Solving	~9	Sections 2.2, 2.3, 3.1 pp. 42-69, 74-89	Acceleration due to Gravity
Vector Analysis	~2	Section 3.3 pp. 90-103	
Relative Motion	~2	Section 3.3 pp. 104-105	
Unit 2: Dynamics (~19 classes)			
Unit/Section Title	# Classes	Text Section/Pages	Suggested Core Investigations
Dynamics Introduction	~6	Sections 4.1, 4.2 pp. 126-136, 145-146	
Newton's Laws	~10	Sections 4.2, 5.1, 5.2, 5.3 pp. 137-144, 154-167, 177-188	Friction Newton's Second Law
Momentum Introduction	~3	Sections 5.4 pp. 195-205	Bumper Construction (impulse momentum)
~ Mid-Term			

Instructional Planning (Term 2)

Unit 3: Momentum and Energy (~19 classes)			
Unit/Section Title	# Classes	Text Section/Pages	Suggested Core Investigations
Work, Power, and Efficiency	~8	Sections 6.1, 6.2, 6.3, 6.4 pp. 216-228, 233-254, 262-271	Pulley Lab. (work/efficiency)
Transformation, Total Energy, and Conservation	~8	Sections 7.1, 7.2 pp. 278-289, 301-309	Law of Conservation of Energy
Conservation of Momentum	~3	Section 7.3 pp. 310-326	
Unit 4: Waves (~22 classes)			
Unit/Section Title	# Classes	Text Section/Pages	Suggested Core Investigations
Fundamental Properties	~6	Sections 8.1, 8.2, 8.3, 8.4 pp. 335-370, 411-414	Wave Speed in a Spring
Sound Waves and Electromagnetic Radiation	~16	Sections 9.1, 9.2, 9.3 pp. 374-380, 385-410, 415-431	