

The Impact of Computer Simulation on the Development of the Inquiry Skills of High School Students in Physics

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Abstract

The purpose of the study was to compare the effectiveness of visualization of natural phenomena via computer simulation and manipulations of concrete objects, in a physics laboratory, on the development of students' inquiry skills in mechanics. A quasi-experimental method that employed the 2 Learning Tools $\times$ 2 Time of learning split-plot factorial design was applied in the study. The sample consisted of 54 Grade 11 students from two physics classes of the university preparation section in the Ottawa-Catholic School Board. One class was assigned to interactive computer simulations (treatment) and the other to concrete objects in physics laboratory (control) as learning tools. Both tools were embedded in the general framework of the guided-inquiry cycle approach. The results showed that the interaction effect of the Learning Tools $\times$ Time of learning was not statistically significant. However, the results also showed a significant effect on the development of students' inquiry skills (indicated by the pre- and post-inquiry skills test) regardless of the type of learning tool they had used. The findings suggested that these two strategies are effective in developing students' inquiry skills in mechanics.

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Dedicated to

my beloved parents,

my small family: Fatma and little Dania,

&

my brother and sisters.

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Chapter 1: Introduction

This introductory chapter outlines learning through inquiry from different perspectives, describes its importance in science education, and emphasizes the potential benefits and challenges for science learners. The role of computer simulation and concrete objects as learning tools will be presented as one of the approaches in enhancing inquiry-based learning. These issues are presented and elaborated under the following sections:

Section 1.1 presents the perspectives of a body of research about inquiry-based learning, and describes how learning through inquiry provides opportunities for students not only to acquire skills and abilities to conduct investigations about natural phenomena, but also to construct better understanding of scientific concepts and theories.

Section 1.2 presents an overview of the difficulties facing the implementation of inquiry in classroom. Accompanying that are the efforts of academic researchers and educators to provide possible educational solutions.

Section 1.3 explores the role of learning tools in enhancing inquiry learning, more specifically, cognitive tools such as the visualization of physical phenomena via interactive computer simulation and the manipulation of concrete objects in the physics laboratory.

Section 1.4 describes the physics content of the study, and explains why it is important to learn it with cognitive tools. Finally, section 1.5 states the significance of this research study and the research questions.

1.1 Inquiry-based learning

It is generally accepted that Dewey (1938) is the founder of inquiry-based learning . However, some trace it back to Socrates and his approach of questioning leading to development of self-knowledge. Inquiry learning is a student-centered approach that “stress[es] the importance

of learning and the process of science such as formulating empirically investigable questions and supporting claims with evidences” (Kubicek, 2005, p.3). Others consider learning science through inquiry as an opportunity to engage students in activities similar to those found in real scientific research, which basically includes reasonable understanding of how scientists do their work (Apedoe, 2007). Wilson (1995) defined inquiry-based environment as “a place where learners may work together and support each other as they use a variety of tools and information resources in their pursuit of learning goals and problem solving activities” (p.29). Nevertheless, the definition that will be used in this study refers to inquiry learning as “the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world” (National Research Council [NRC], 2000, p.1). Thereby, students will actively investigate about natural phenomena by posing questions and seeking answers to these questions. In doing so, students acquire abilities and skills to understand concepts, models and theories in a way that reflects how the natural world actually works (Al Byers & Fitzgerald, 2002; Bybee, 2000; Ketelhut, 2007; Kipnis, 2007).

Inquiry-based learning has become, to many educators and academic researchers, one of the approaches to teach and learn science across different levels of education. The central goal of this approach is to engage students in learning activities to develop meaningful understanding and construct scientific explanations by exploring natural phenomena. Instead of memorizing definitions and facts, students need to acquire, clarify and apply knowledge to master situations that resemble real life situations (Cronin, 1993). The call for inquiry-based learning is based on the recognition that science is essentially a question-driven process and that students must have personal experience with scientific inquiry to understand this fundamental aspect of science (National Research Council [NRC], 1996). Such an approach has pushed for much more

emphasis on the need to involve students in inquiry activities that promote critical thinking (Akkus, 2007), and scientific reasoning (Chinn & Malhotra, 2001).

Inquiry-based approach tends to invite students to investigate the world around them in order to ask questions and solve problems, construct mental models of phenomena, and understand procedures that scientists use in their work. Therefore, inquiry provides opportunities to develop specific investigation skills such as posing questions, formulating hypotheses, designing and conducting investigations, and gathering and analyzing data (Kuhn, 2008; NRC, 1996). Many members of the science education community believe that acquiring appropriate level of inquiry skills is important to foster inquiry learning and its related instructional goals (Hofstein, 2004; Ketelhut, 2007; Kuhn, 2008). For example, abilities to pose questions lead students to recognize gaps in their preexisting knowledge and a curiosity to resolve a problematic situation. Planning procedures and conducting investigations are required for students to construct explanations and knowledge in order to complete the investigation successfully. Gathering and analyzing data provides a chance for students to pursue answers to questions and apply their new scientific understanding in ways that will support its future use (Wu, 2006).

Generally, when learning science through inquiry, students are expected to reap the following benefit (Hofstein, 2004; Ketelhut, 2007; Wu, 2006):

- recognize the use of scientific methods, such as stating hypotheses, assumptions, predictions and conclusions;
- increase motivation to learn science;
- promote habits of mind associated with science practices;
- understand, interpret and analyze scientific phenomena, and transfer this understanding to new contexts;

- exchange ideas among peers and challenge others thinking;
- learn to think scientifically and understand the relationship between evidence and theory.

Despite these outstanding benefits, the effectiveness of inquiry learning is diminished by intrinsic problems many students have with this mode of learning (Reid, 2003).

1.2 Kind of difficulties facing the implementation of inquiry learning in classrooms

A number of difficulties prevent students from successful engagement in meaningful investigation which undermines learning through inquiry. The major difficulty which is tackled throughout this study is the development of adequate level of students' inquiry skills. Skills such as posing questions and identifying variables, formulating hypothesis, designing and conducting investigation, collecting and analyzing data, should not be taught like general science principles. They should be experienced while students are engaged in inquiry activities repeatedly in their science lessons presumably enriching, and expanding their skills with each engagement (Kuhn 2008). Due to inadequate level of inquiry skills students often learn science through direct observations and problem solving tasks without spending efforts to experience natural phenomena, or construct abilities and knowledge to understand how the natural world works (Manlove, 2006; Reid, 2003). Although studies on the development of inquiry skills have provided little guidance about how students acquire and develop these skills over time, some research studies show that factors like students' self-efficacy, effective scaffolding, and collaborative learning environments may have an impact on students' abilities and skills to progress through inquiry tasks (Ketelhut, 2007; Reid, 2003). For example, Wu (2006) reported that students improved their inquiry skills after they had practiced them in a series of inquiry-based activities. In the same stream White (1998) designed a planning framework within the

curriculum to scaffold students' inquiry and modeling activities. The finding in this study showed that students who had access to effective scaffolding during the performance of inquiry tasks surpassed students who received no such support.

Despite the fact that lacking adequate level of inquiry skills is considered one of the major difficulties that confronts inquiry learning (Hofstein, 2004; Ketelhut, 2007; Kuhn, 2008), other factors such as motivation, preexisting content knowledge, students' organization, and management skills, are important to comprehend in order to give more insights to the obstacles facing inquiry-based learning¹.

First, Soloway (1994) recognized that developing *motivation* plays an important role to engage students in inquiry learning environment. The extended nature of inquiry tasks and activities demands a higher level of motivation on the students' part than is required by traditional educational activities (Soloway, 1994). One way to develop motivation is to draw students' interests to the investigation by engaging them in discussions about natural phenomena. During these discussions, students may ask questions and raise issues to be explored in subsequent phases of inquiry (Al Byers & Fitzgerald, 2002).

Second, the formulation of a research question, the development of a research plan, the data collection and analysis, and the interpretation of data all require preexisting *content knowledge* in science (Brown, 2006). If students lack this knowledge or the opportunity to develop it, they will be unable to understand new concepts and complete a meaningful investigation successfully (Brown 2006; Quintana, 2004). In that respect, tests of conceptual understanding are useful instruments to predetermine the status of students' understanding or misunderstanding of science concepts. With such diagnostic information at the teacher's

¹ This study will not measure the other factors like motivation, preexisting knowledge, and students' organization and management skills that confront inquiry learning.

disposal, the teacher can choose teaching methods to implement and compensate students' knowledge deficiencies.

Finally, inquiry activities encourage students to organize and manage complex and extended activities. Unlike inquiry skills, *management skills* allow students to plan, and coordinate inquiry activities, manage their learning resources, work products, learning tools, and learning environment. If students are unable to organize their work and manage an extended process, they may not be fully engaged in authentic inquiry learning or achieve its potential (Harris & Rooks, 2010). Thus, providing students with worksheets could be one of the ways to manage their inquiry learning (Njoo & De Jong, 1993). However, too much guidance should be avoided to provide students with more freedom to decide how to proceed or monitor their inquiry learning.

As a summary, two types of problems facing the authentic implementation of inquiry learning have been identified: problems related to students' deficiencies in knowledge and inquiry skills, and problems related to practical constraints and organization and management of learning. While previous studies made progress in tackling problems related to organization and management of learning, further research should be done to provide specific guidance to develop students' inquiry skills.

1.3 Role of learning tools

Learning tools encourage students to be cognitively active, provide hints, and prompt students to explore complex problems on their own. Students use learning tools to reinforce previously learned information and develop skills and abilities to a more fluent level. Drill-and-practice worksheets, as an example, have been widely used to develop students' mathematical skills (Jonassen, 1996).

The stepping stone of computer technologies elevated the role of learning tools to another level. New learning tools such as computer software programs can be utilized to present complex problems in classrooms and assist students to construct new knowledge in situations where it would be potentially useful. Micro-computer Based Laboratory, another example, allows learners to measure physical quantities (such as time, distance, speed, acceleration, and force) by concrete sensors that are interfaced with computers. Students can gather data and transfer it to the computer for further analysis. This tool integrates the benefits of concrete experiments with the effectiveness of computer capabilities (Thornton & Sokoloff, 1990).

Nevertheless, some researchers have conducted extensive studies to identify, and to explore the types of learning tools that are potentially useful to help students to construct knowledge, and to develop inquiry skills (Hofstien, 2004; Jonassen, 2004; Kuhn, 2007). For example, great promises have been given to the visualization of natural phenomena via interactive computer simulation (Abdullah, 2006), and the manipulation of concrete objects in science laboratory (Hofstien, 2004).

Interactive computer-based simulation

Computer-based technologies provide support for nearly every aspect of scientific inquiry (Windschit, 2000). New computer technologies have evolved now to the point they can contribute to the development of students' learning through inquiry, and allow teachers to meet students' needs more fully (Foti & Ring, 2008). Learners use various types of new technologies to collect, organize and analyze data, transform data into variety of representations, create virtual situations in which they can test hypothesis, and even synthesize and execute their own models (Kubicek, 2005; Windschit, 2000).

Computer simulation is a type of technology that models natural phenomena and provides resources both for exploring the principles that govern a particular domain and opportunities for feedback, reflection, and revision. With interactive simulation, students will be supported to manipulate variables, observe effects on a phenomenon simultaneously, and get feedback on their own work. Research studies indicate that the visualization of phenomena through computer simulation could help students to understand events that were difficult to perform by concrete objects in school laboratories (Cadmus, 1990; Fernandez, 2003); enhance students' conceptual understanding (Zacharia, 2003); and promote integration of knowledge by connecting familiar objects with science concepts (Snir, 1993). In the domain of atomic physics, for example, high school students and many college students have misconceptions about how electrons are arranged and interact in the atoms. Simulations that describe the atomic structure contribute to student's understanding of physics at the atomic level by attaching mental images to these concepts (Abdullah, 2006; Cadmus, 1990), allowing students to create and test their atomic models, and giving feedback to students' thinking and understanding of the atomic structure.

Moreover, interactive computer simulations can provide various functions, setups, and control buttons to help students run physical phenomenon several times. In a self-directed process, students can control variables, establish relationships, investigate about a problem and reduce human errors that are associated with experiments in real laboratory settings (Escalada & Zollman, 1997; Fernandez, 2003). Although students benefit greatly from the opportunity and responsibility of exploring complex problems, scaffolding must be provided to help students carry out the parts that they cannot yet manage on their own. According to Vygotsky, less skillful students will have a better opportunity to develop more complex level of skills through guidance, collaboration, or help from an expert or a more capable peer (Rosenshine & Meister, 1992).

Despite the potential advantages of computer technologies in enhancing inquiry-based learning, it is important to note that the use of computer-based simulation has certain potential drawbacks as well, and therefore, must be taken into consideration. For example, computer-simulated experimentation software dictates the direction of inquiry by predefining variables. Even though simulations can be interactive, students cannot test alternative models or novel variables that are not programmed into the system, and the opportunity to identify variables on their own is not available. Another cautionary note about simulations concerns their effect on the representation of reality. Maxwell (1999) said that due to the visual nature of computer simulation and the distorting mediation of computers, physical representations of natural phenomena may be denied. As a consequence, some researchers have suggested that computer simulation should not be used to replace real experiences, but rather to supplement them (Feldman, 2000).

Manipulation of concrete objects in science laboratory

A body of research studies has considered inquiry-based laboratory as one of the ways students can understand the natural world of science and develop their inquiry skills. If students were given an opportunity to perform a properly developed inquiry-based activity, they would be able to utilize concrete objects to understand the nature of science, develop experiences of natural phenomena, and practice inquiry skills (Hofstein, 2004; Kipnis, 2007).

When a laboratory investigation is constructed in a problem solving context, students will be required to plan a course of action, carry out the activity and collect necessary data, organize and interpret the data, and reach a conclusion. This type of laboratory investigation encompasses both the ways in which understanding is generated within the natural sciences and an approach to

solving problems, as well as attaining inquiry skills and understanding the process of scientific protocols.

In the laboratory setting, students are often engaged in a variety of active learning methods such as manipulating concrete objects and materials, pacing the work as it suits them, interacting more freely with the teacher, and initiating discussions with other peers in small groups or with the whole class. The inquiry environment may develop positive attitudes to science investigation and understanding of the natural phenomena. Attitudes to science include interest, enjoyment, satisfaction, confidence and motivation. For example, Trumper (2002) described a couple of physics experiments in which high school students used concrete objects such as an optics bench, a ray table and base, a slit plate, light source to measure the index of refraction. Students had the opportunity to think and feel like physicists when they were involved in various scientific methods of inquiry and utilized them in their own investigations.

Although science laboratory has been given a distinctive role in science education, research has failed to show simplistic relationships between experiences in the laboratory and student learning. Hodson (1990) criticized laboratory work and claimed that it is unproductive and confusing, since it is very often used unthinkingly without any clearly thought-out purpose, and called for more focus on what students are actually doing in the laboratory. Tobin (1990) claimed that, in general, research has failed to show evidence that students are given actual opportunities to manipulate concrete objects and materials to be able to construct their knowledge of phenomena. Gunstone (1991) suggested that using the laboratory to have students restructure their knowledge is naive, since the picture relating to practical work as derived from constructivism is more complicated. He also suggested that learning in the laboratory would occur if students were given ample time and the opportunities for interaction and reflection in

order to initiate discussion. According to him, this approach is under-used, since students in the science laboratory are usually involved in technical activities (such as assembling the experimental setup) and few opportunities are given to them to present their interpretation and beliefs about natural phenomena. Therefore the focus of laboratory activities should not be limited to learning particular laboratory techniques, instead, students should use the methods and procedures of science to investigate phenomena, solve problems, and pursue their inquiry and interests (Hodson, 1990).

All in all, the visualization of natural phenomena via computer-based simulation and the manipulation of concrete objects in science laboratory, both, have advantages as well as potential difficulties and limitations (Table 1.1).

Table 1.1 Impacts and limitations of computer simulations and science laboratory on the construction of knowledge and the development of inquiry skills

	Computer simulations	Science laboratory
Impacts on the construction of knowledge	Computer simulations are expected to: • Provide resources to explore natural phenomena. • Give opportunities for feedback, reflection, and revision. • Simulate phenomena that are difficult to perform in real experiments. • Allow students to observe events over and over	Science laboratory is expected to: • Support the physical representation of natural phenomena. • Enhance collaborative work. • Allow more interactions with teacher. • Develop positive attitude towards science investigations and how scientists do their work.
Impacts on the development of inquiry skills	Computer simulations are expected to: • Facilitate the manipulation of variables. • Transform data into variety of representations. • Eliminate the human errors associated with measurements (accuracy and precision). • Allow students to design and test their own models easily.	Science laboratory is expected to: • Engage students in a variety of active learning mode. • Allow students to design real experimental setup. • Give opportunity to manipulate equipment and materials. • Allow students to test their models.
Limitations	Computer simulations: • Dictate the direction of inquiry by predefining variables. • Do not allow students to test alternate models that are not programmed. • Disregard the physical representation of natural phenomena.	Science laboratory: • Involves technical challenges that drive students off task. • Does not offer sufficient time to manipulate equipment. • is challenged by improper development and performance.

(Fernandez, 2003; Gunstone, 1990; Hodson, 1990; Kipnis, 2007; Maxwell, 1999)

These limitations, however, could prevent students from having an authentic opportunity to develop adequate level of inquiry skills and consequently undermine their efforts to construct knowledge and engage in inquiry-based learning (Kuhn, 2000; Windschit, 2000).

The current study, therefore, attempts to compare the impacts of two teaching strategies on the development of students' inquiry skills in the domain of physics. One strategy will integrate computer simulation and another strategy will integrate concrete objects as learning tools. In this regard, the main objective is to find out which learning tool is more suitable to help students develop their inquiry skills and in which learning circumstances.

Prior to explicating the purpose and the objectives of this research work, a brief overview of the subject content is given in the next section in order to highlight the rationale of the context.

1.4 Physics content

Physics is sometimes called the *fundamental science*. It covers a wide range of natural phenomena, from elementary particles to the largest super-clusters of galaxies. Physics aims to describe the various phenomena that occur in nature, and develop mathematical models to express these phenomena and successfully predict future events. It involves the study of matter and its motion through space-time, as well as all applicable concepts including energy and force. The latter are grouped in a set of rules and principles to form the basis of classical mechanics, from which Newton's laws of motion are chosen to be the subject content of this study.

Newton's laws of motion are one of the fundamental concepts in classical mechanics. They are a set of three physical laws that give accurate description to the motion of objects, and mathematically express the relationships between different variables such as force, mass, acceleration, momentum, and impulse. Newton's laws are an important part of physics

instruction at different levels. Students learn the fundamental concepts of motion and forces in elementary school and gradually they are expected to integrate more complex ideas into these basic concepts throughout their high school education (The Ontario Curriculum Grades 11 & 12, 2009). Newton's laws are not only very rich in content area, but also provide a good context for experiencing different types of inquiry skills (Espinoza, 2005). Newton's second law experiment, for example, requires students to predict the motion of physical bodies, identify factors affecting object's motion, analyze the gathered data, interpret graphical representations of motion, and draw conclusions. Further, Newton's second law involves solving numerical problems, identifying and analyzing different types of forces (such as gravitational, friction, tension, and centripetal force), and interpreting various forms of graphs. As a result, this physics content seems very suitable for this study.

Students face many challenges while studying Newton's laws of motion (Espinoza, 2005). This content area, in fact, requires preexisting knowledge in order to construct. Students in elementary level learn simple concepts and relationships between different physical quantities, such as time, distance, and uniform speed. When the concept of force is introduced more complex relationships emerge, such as the relationships between net force vs. mass, force vs. change in velocity; change in momentum vs. time; and mass vs. acceleration in uniform and non-uniform motion. Students at this stage are required to develop abilities to "analyze the motion of objects, using vector diagrams, free-body diagrams, uniform acceleration equations, and Newton's laws of motion" (The Ontario Curriculum Grades 11 and 12, 2009). This level of difficulty and complexity, however, requires students to have appropriate inquiry skills in order to construct knowledge about the nature of forces and explanations about how these forces inter-relate in nature.

In general, the complex nature of mechanics inspired a body of academic researchers to conduct various types of investigations to foster the methods of teaching and learning Newton's laws of motion (McDermott, 1987, 1996; Smith, 2007; Thornton, 1998). Much of this research focused on the development of students' conceptual understanding and their abilities to carry out inquiry-based activities successfully (Escalada & Zollman, 1997).

1.5 The research study

There is a significant need to investigate how learning tools are effectively utilized to develop students' inquiry skills in the context of Physics. First, although, studies on inquiry learning have recognized the importance of developing students' inquiry skills (e.g., White & Frederiksen, 1998), there is little guidance about how inquiry skills can be developed over time.

Second, previous researchers have identified the potentials of visualization of phenomena via computer simulations with respect to the development of students' reasoning skills and conceptual understanding of physics (e.g., Abdullah, 2006; Cadmus, 1990; Escalada, 1997). However, there are few studies investigated the effectiveness of visualization tools on the development of inquiry skills.

Third, another line of research studied the potential impact of the manipulations of concrete objects in science laboratory on students' conceptual understanding and the development of their inquiry skills in chemistry (e.g., Hodson, 1990; Hofstein 2004; Kipnis & Hofstien, 2007). This signals the need to conduct more research in order to cover a wider range of science disciplines.

The following research questions will guide the research study:

1. What are the possible impacts of the visualization of Newton's second law of motion via interactive computer simulation on the development of students' inquiry skills?

2. What are the possible impacts of the manipulation of concrete objects to perform Newton's second law experiment on the development of students' inquiry skills?
3. How are the effects of the utilization of computer simulation and the manipulation of concrete objects compared?

Chapter 2: Theoretical Framework

This chapter furnishes a conceptual framework to justify the utilization of two cognitive tools in guided-inquiry learning environment in enhancing students' inquiry skills. This theoretical framework is described in the following order:

Section 2.1 outlines the constructivism view of learning science as a continuous process of constructing and reconstructing new concepts in a socially situated learning environment.

Section 2.2 describes the importance of learning science as inquiry, as well as rationale of the framework required to guide students through inquiry phases.

Section 2.3 justifies further arguments about the need to develop students' inquiry skills in order to progress through inquiry phases and tasks.

Finally, Section 2.4 presents the research objectives on the basis of the theoretical framework.

Learning science in different school levels has often been centered on authoritative source of knowledge (textbooks and teachers). Students learn science by reading from a textbook or listening to a teacher (Davis, 2008; Glynn, 1991). However, another view of learning science has emerged aiming to focus not only on what students are able to do, but also on what they are able to think.

2.1 Constructivism and learning science

Constructivism view of learning considers learning as a construction and reconstruction of knowledge through a cognitive development or social interactions. The argument is that, learning takes place when new information is built into and added on to an individual's current structure of knowledge, understanding, and skills (Pritchard, 2005).

According to this view, students learn better when they are actively constructing their own understanding and able to reflect it in representations such as graphs, mathematical equations, tables, and charts. This allows students to understand the significance of scientific information so it can be used in the future as a tool to synthesize evidence, resolve problems, and making appropriate decisions (Pritchard, 2005). When students learn how to reason with and about knowledge, they will be able to adapt to new environments and make decisions about what they know and what they need to learn (Pritchard, 2005).

It should also be stressed that the role of teacher in the constructivism paradigm is actually centered to provide students with the necessary aids so they can actively engage in learning and attempt to construct scientific knowledge and skills. To do that, teachers can bring interesting and complex problems about natural phenomena. As well as provide opportunities to explore these problems through experimentations or observations, enhance communications using scientific terms, and support collaborations in science laboratory or classroom. Such a role is critical to develop student's skills to acquire deeper understanding of the scientific concepts and principles (Davis, 2008; Linn, 1996; NRC, 1996).

Therefore, constructivism aims not only to guide students towards the acquisition of scientific knowledge, but also to provide them with experiences that challenge and enlarge their understanding of the natural world. It is through these experiences that students can develop skills and abilities in a way that make learning science significant.

2.2 Learning science as inquiry

It is commonly accepted that inquiry approach is rooted to constructivism epistemology, in which learners are independently or socially constructing meaningful concepts and integrating new knowledge into their preexisting mental models of the natural world (Abdul Haqq, 1998;

Richardson, 1997). Some educators view learning science through inquiry as an approach to learn scientific investigation, and to understand how scientists do their work (National Research Council [NRC], 2000).

Inquiry learning is categorized into four levels based on the degree of students' engagement in their learning (Herron, 1971). Starting at zero where the problem, procedures and solution are all given by the teacher, going through structured-inquiry and guided-inquiry in level 3 – to open-inquiry where the problem is student-formulated, the procedures are student designed and selected, and seeking a solution that is not known in advance.

In this study, guided-inquiry is used as an approach of learning, in which students investigate teacher-presented questions and later determine both processes and solutions. Although, in guided inquiry the questions are supplied by the teacher, the students actually lead the inquiry process to seek unforeseen conclusions.

One may ask why learn science through guided-inquiry? Part of the answer has been provided by Piaget (1964), who argued that learning is a continuous process of updating one's sense of the world as prompted by new experiences. As a consequence of this view, one may formulate the following pedagogical principle: The learner is constantly constructing and reconstructing knowledge in an effort to maintain coherent system of interpretation (Davis, 2008). A second part of the answer has been provided by Vygotsky (1978), who argued that students are capable of performing at higher intellectual levels when they are guided by an experienced person, and asked to work in collaborative situations. The latter constitutes the second pedagogical principle of this research. More specifically, he hypothesized that the social interaction among students will extend their zones of proximal development. The zone of proximal development is defined as the distance between the level of student's ability to learn

without help and the level of potential development under adult guidance, or in collaboration with more capable peers (Abdullah, 2006).

Based on these two principles, students in guided-inquiry environment are expected to be exposed to inconsistencies in their attempts to construct new concepts. This exposure creates a desire to resolve incongruities between prior understanding and new information, and accompanied, therefore, by feeling of disequilibrium. Especially, whenever new science concepts raise questions or complexities that cannot be resolved with students' prior knowledge or experiences (Abdullah, 2006). Therefore, feeling of disequilibrium can be resolved by providing proper guidance to help students carry out the parts of the inquiry task that they cannot yet manage on their own (Abdullah, 2006).

There is more than one way of looking at the required type of proper guidance. On one hand, students may receive guidance while they interact with more capable persons (such as teachers). This interaction could take different forms including modeling good thinking, coaching, collaboration, and providing hints or reminders about the procedures that are important for inquiry learning. On the other hand, one may look at the ways how inquiry tasks are designed. They could be designed in a logical pattern or categories based on the level of complexity. So students may begin with exploring natural phenomena and progressing through to end with applying the new concepts in new situations. Eventually, students may gradually develop their pattern of thinking that is driven from their new learning experiences, and therefore, promote a new state of understanding of the new concepts to reach the level of equilibrium.

This structure of guidance brings us to a conclusion that whether students learn in collaborative groups or by themselves in a classroom they need to interact with a more capable

person(s) in order to progress through their learning of scientific concepts. One way to do this is through the 5Es learning model, which will take the major role in the design of the teaching strategy of this study.

Guided-inquiry model: 5Es learning cycle

The 5Es is an instructional model based on the constructivist approach to learning (Bass, 2009). The model consists of five phases: *engage*, *explore*, *explain*, *elaborate*, and *evaluate* (Renner, 1985). The 5Es model allows students and teachers to experience common activities, to use and build on prior knowledge and experience, to construct meaning, and to continually assess their understanding of a concept. Thereby, students can be engaged in learning activities that are designed to help them make connections between their prior and current learning experiences. These activities are expected to focus students' thinking on the learning outcomes, and help them to become mentally engaged in the concept, process, or skills to be practiced. Therefore, progressing through the 5Es phases requires students not only to receive proper guidance, but also to have adequate level of skills and abilities so they can accomplish their tasks successfully.

Inquiry skills

Academic educators, such as Kirchner (2006), believed that acquiring adequate level of inquiry skills is very important to progress through inquiry tasks and phases. Students are expected to work more independently, observe details, compare and contrast, design experimental procedures, collect and analyze data, predict sequence of events, and link cause and effect. Such abilities are vital to meaningful inquiry activities.

Therefore, students, in inquiry environment, need to have adequate level of certain skills and abilities to produce solutions to problems such as:

- Identifying variables.

- Formulating hypothesis
- Gathering and analyzing data
- Identifying graph that represents the data, and describe the relationship between variables.
- Designing and conducting investigation

(Burns, 1985; Hofstein, 2004; The Ontario Curriculum Grades 11 and 12, 2009)

In this study, these skills are referred to as inquiry skills that are necessary for inquiry learning. They cannot be taught or learned at one discrete time. Rather, it is prescribed that students engage in inquiry activities repeatedly, presumably enriching and expanding their inquiry skills with each engagement (Kuhn, 2005). If students lack these necessary skills, inquiry learning could in fact be counterproductive, leading students to frustration and to the conclusion that the world, in fact, is not analyzable and worth trying to understand – a conclusion that runs exactly opposite to the intellectual values that inquiry learning would promote (Kuhn, 2000; Resnick, 1997).

Over all, the importance of acquiring appropriate level of inquiry skills brings us to the question of how these skills and abilities can be developed during the repeated engagement of students in inquiry activities. One of the answers relies on the opportunities given to students to learn with cognitive tools.

2.3 Learning with cognitive tools

Cognitive tools such as computers, tutorials, concrete objects are able to exhibit natural phenomena into the inquiry environment. When cognitive tools present natural phenomena as real-life problems, students might be able to receive feedback and reflection on their attempts to solve these problems. The aspects of feedback and reflection are critical to developing the

abilities required to help students investigate natural phenomena. In the context of learning, feedback and reflection weigh students' performances while obtaining data, as well as their predictions about the outcomes of the investigation (Dewey, 1938; Jonassen, 1996).

The argument is that, while investigating natural phenomena, learners receive feedback from their performance associated with cognitive tools, and accordingly they may feel a need to adjust their performance in response to it. This may raise students' awareness of their inquiry skills deficiencies and encourage them to think how to correct them. Therefore, students tend to engage in inquiry investigations repeatedly to practice their inquiry skills and consolidate them in each engagement (Kuhn, 2005).

Analysis on performance with cognitive tools indicates that the development of inquiry skills takes lots of practice over a long period of time. Cycles of feedback, reflection, and opportunities for revision allow students to effectively practice with cognitive tools using the inquiry skills they are trying to master (Jonassen, 1996; Kuhn, 2000; Linn, 1987).

This brings us to the questions of how cognitive tools can provide opportunities to practice inquiry skills, and allow students to receive feedback on their performance. More important, how cognitive tools present natural phenomena as real-life problems in a meaningful way.

Many cognitive tools show great promises in supporting the development of inquiry learning and modeling expertise (Kubicek, 2005; Windschit, 2000) such as:

- Computer software allows learners to test their own models of natural phenomena. Some of these software programs scaffold novice modelers by representing parts of a system with concrete images, and the connections between elements of the model with

qualitative descriptions. Other modeling software deals with abstract representations and requires learners to express relationships between variables as mathematical equations.

- Visually enhanced data collecting tools, such as Micro-computer Based Laboratory (MBL), allow learners to instantly measure physical quantities using sensors, and to transfer the collected data to a computer. The computer is often interfaced with the sensors, and allows students to conduct further analysis.

However, the recommendation here would be suitable for the purpose of this study, to look at two specific cognitive tools: interactive computer simulation (Jonassen, 1996), and the manipulation of concrete objects in a physics laboratory (Hodson & Hofstein, 2004). These two options are commonly used in learning environments because of their flexibility to create educational environments that model real-life events.

Visualization of natural phenomena via interactive computer simulation

Computer simulation is referred to the type of software program that simulates a physical phenomenon when it is hard to experience it in a natural setting (Gibbons, 1997). To be interactive, computer simulations should allow students to make adjustments on the representations of the natural phenomena in a way they can receive feedback from the simulation after each attempt.

According to the constructivist view, interactive computer simulations assist students to investigate natural phenomena when they are presented as real-life events. In doing that, computer simulations provide students with features and functions to collect data and transform it into different types of graphical representations. The various types of data representations allow students to analyze data and make interpretations of events in terms of their existing cognitive structure (Abdullah, 2006).

Interactive computer simulation can provide a suitable medium to test relationships between variables by altering parameters, plotting graphs as the simulation runs, and investigating extreme situations. As a result, computer simulations give students opportunities to design experiments to test hypothesis, analyze complex relationships, and choose alternative strategies to proceed when others fail.

Similarly, other cognitive tools can often be utilized to foster students' inquiry skills by manipulating concrete objects in more realistic experiences in science laboratory.

Manipulation of concrete objects in science laboratory

Meaningful learning in science laboratory might occur when students are given sufficient time and opportunities for feedback and reflection (Champagne, 1990). In science laboratory, feedback and reflection can be associated with inquiry activities, especially when they are conducted in the context of meaningful problems.

Let us begin by looking at opportunities offered to engage students with meaningful problems. On one hand, bringing real-life problem in science laboratory may allow students to exercise their inquiry skills. This process involves conceiving problems and scientific questions, formulating hypotheses, designing experiments, gathering and analyzing data, and drawing conclusions about scientific phenomena (Hofstein, 2004; Kipnis, 2007).

On the other hand, providing students with concrete objects in inquiry activities would logically assume that students will receive feedback on their performances while utilizing concrete objects to conduct their investigation. As a result students would practice their inquiry skills as they are involved in actions that constitute an integral part of the inquiry laboratory activity including correcting errors, suggesting alternative procedures, and seeking reasons for aspects of current work (Hofstein, 2004; Kipnis, 2007).

As for the effectiveness of the manipulation of concrete objects in science laboratory, four conditions are necessary to induce proper practice of inquiry skills: time, opportunity, guidance, and support (Hofstein, 2004). In the inquiry laboratory students should get ample time to observe natural phenomena, and opportunities to collect and analyze data. The ample time would be necessary for understanding the inquiry tasks, and practicing the inquiry skills. The teacher is expected to guide students and provide them with the necessary supports (such as resources and suitable equipment) in order to accomplish their inquiry tasks successfully (Hofstein, 2004; Kipnis, 2007).

In conclusion, it seems likely that both cognitive tools (computer simulation and concrete objects) can be utilized to assist students in developing their inquiry skills. Students may get feedback from both cognitive tools to help them practice their inquiry skills more effectively. However, research has yet to determine which of the above stated cognitive tools are more effective (Hofstien, 2004; Zacharia, 2003). The current research, therefore, attempts to offer empirical evidence of their effectiveness.

2.4 Research objectives

The theoretical framework of this study is based on Piagetian and Vygostkian views. The argument is that cognitive tools can be utilized to function as intellectual partners with learners in order to develop their inquiry skills. Teacher guides and peer interaction will present additional experiences that will lead students to complete inquiry tasks and phases more efficiently. Through feedback and reflection in the 5Es learning cycle, students' inquiry skills are expected to progress and deal with inquiry tasks more fluently. Consequently, the integration of the 5Es learning cycle with cognitive tools can increase the level of inquiry skills of students in physics. Therefore, the main purpose of the study is to compare the effectiveness of visualization

of natural phenomena via interactive computer simulation and manipulation of concrete objects in a physics laboratory on the development of students' inquiry skills in the context of Newton's 2nd law of motion.

Chapter 3: Teaching Strategy

This chapter describes two teaching strategies, and their implementations in two learning environments: computer-based simulation and physics laboratory. The teaching strategies are described in the following order.

The first two sections describe the guided inquiry-based approach as a context of inquiry learning. Within this context, a learning cycle is adopted to guide students through inquiry tasks and phases in order to accomplish their targeted learning objectives.

Section 3.3 emphasizes the pedagogical roles of the assigned learning tools and materials in fostering students' inquiry skills.

Section 3.4 describes how the teaching strategies can be implemented in computer-based simulation and physics laboratory learning environments. Special attention is given to the role of teacher, and what is expected from students to do in the learning activities.

Finally, Section 3.5 reports the actual implementation of the two strategies, and highlights to what degree they match with the actual plan.

3.1 Teaching and learning objectives

The overall learning objectives are set for students to “demonstrate scientific investigation skills (related to both inquiry and research) in the four areas of skills: initiating and planning, performing and recording, analyzing and interpreting” (The Ontario Curriculum Grades 11 and 12, p.182). Throughout the learning activities, students are expected to develop inquiry skills to be able to:

1. Identify variables such as forces, mass, time, speed, velocity, acceleration, friction, gravity, and normal force.

2. Conduct an inquiry that applies Newton's [second law] to analyze, in qualitative terms, the forces acting on an object, and use free-body diagrams to determine the net force and the acceleration of the object.
3. Design and conduct an inquiry into the relationship between the acceleration of an object and its net force and mass, and analyzing the resulting data.
4. Analyze the relationships between acceleration and applied forces.
5. Plan and conduct an inquiry to analyze the effect of forces acting on objects in one dimension, using vector diagrams, free-body diagrams, and Newton's laws.

(The Ontario Curriculum Grades 11 and 12, 2009)

The teaching objectives, therefore, will primarily be looking at ways to foster the development of students' inquiry skills and guide them to accomplish their inquiry tasks successfully. The teacher is expected to:

1. establish and maintain a healthy and safe learning environment;
2. implement 5Es learning cycle as a model for learning and teaching through guided inquiry environment (to be discussed in the following section);
3. provide students with the time, space and resources needed for learning;
4. assess students learning as well as the whole class.

Before the discussion of how the teaching and learning objectives will be accomplished, it is important to describe the context for the inquiry learning.

3.2 The context for inquiry learning

Guided inquiry is chosen as a context for inquiry learning. As mentioned in the theoretical framework, guided inquiry is an intermediate level of a broad spectrum of inquiry levels, in which students investigate teacher-presented questions and later determine both

processes and solutions. Although, in guided inquiry the questions are supplied by the teacher, the students actually lead the inquiry process seeking after unforeseen conclusions.

Researchers have agreed that this mode of inquiry learning prevents waste of time, and reduces student frustration due to achieving undesirable results or experiencing failure (Trautmann, & Avery, 2004) – all of which may occur in a more student-directed open inquiry approach. Therefore, guided inquiry gives confidence to students and encourages them to develop high level of inquiry skills (Gallagher & Tobin, 1987; Yen & Huang, 2001; Zion, 2007). To be effective, the inquiry may proceed through cycles of investigations guided by sub-questions or natural phenomena. The 5Es learning cycle will be implemented for this purpose.

5Es Learning Model (Renner, 1985)

Engaging students in a guided inquiry learning environment requires a learning model that embeds the features and characteristics of guided inquiry. 5Es learning cycle (Figure 3.1) is a model that mirrors guided inquiry learning in classroom (Bass, 2009; Llewellyn, 2005).

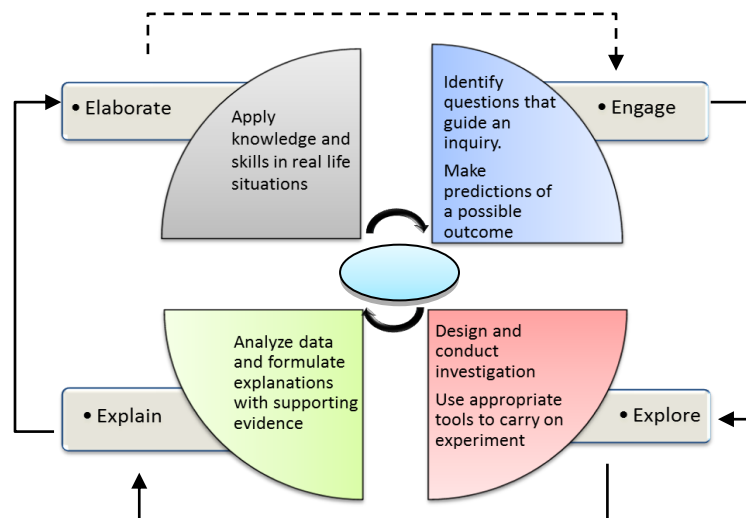


Figure 3.1 5Es learning cycle (Renner, 1985)

The 5Es learning cycle is an instructional model that is employed in classrooms to mirror guided-inquiry process (Bass, 2009; Llewellyn, 2005). The 5Es model has been developed by the Biological Science Curriculum Study group in 1989 to guide students through a learning cycle that incorporates different phases (Bass, 2009; Bybee, R. 1997). The 5Es phases provide structure to guide students through different inquiry processes, tasks, and skills (Bass, 2009).

The model of instruction in 5Es cycle consists of five phases: engage, explore, explain, elaborate, and evaluate (Renner, 1985). These phases are basically embedding all aspects of inquiry process, tasks, and skills (Bass, 2009).

In the engagement phase, students are presented with a physical phenomenon to challenge what they know or believe. Thereby, students will have an opportunity to ask questions about the phenomena to recognize their state of disequilibrium and in what ways their current beliefs fall short. Here, the teacher's role becomes important to raise questions about the target concepts or phenomena and guide students to realize their cognitive conflict, and help them to form predictions or hypotheses to be tested in the next phase. Such predictions can generate curiosity and interest, and encourage students to transfer their prior knowledge to a new state of learning experience.

In exploration phase, students can be actively involved in collaborative groups to test hypotheses and resolve their cognitive conflicts. Thereby, students would have the opportunity to collect data using a variety of cognitive tools. Then transform this data into a graphical representation, so students can make sense of it and interpret it in the next phase.

Explanation phase involves interpretation of events in terms of existing cognitive structure, and with appropriate guidance students can drive the new concepts and principles to promote a new state of understanding or equilibrium.

The elaboration phase provides additional experience to help students discover applications of the newly developed concept. Further, providing additional time for discussions with peer and teacher may assist students to discover other new and related principles to further support the understanding of new concept.

Finally, evaluation phase incorporates formative (ongoing) and summative (end of lesson) methods. In summative assessment, students are expected to answer questions using their observations, evidence, and previously accepted explanations. In formative assessment, the teacher should observe students throughout the learning cycle as they apply new concepts, and the teacher should use benchmark tool to assess their abilities and skills.

For the purpose of this study, students will be assigned to a set of learning tools and instructional materials to ensure that they are able to progress in the 5Es learning cycle and towards their learning objectives.

3.3 Learning tools and materials

The kinds of learning tools and materials are basically selected to support the development of students' inquiry skills. More specifically, they are selected to assist students to formulate answers to the questions that are driving their inquiry tasks. These driving (guiding) questions help students to make predictions, write procedures, conduct investigations, analyze data and formulate explanations. This section defines the main features of the interactive simulations and the concrete objects, their selection criteria, and the forms of text materials students are going to use.

Interactive computer-based simulations

The interactive simulations are selected from the ones available on the **Physics Education Technology (PhET)** website (<http://phet.colorado.edu/index.php>). They are developed and tested

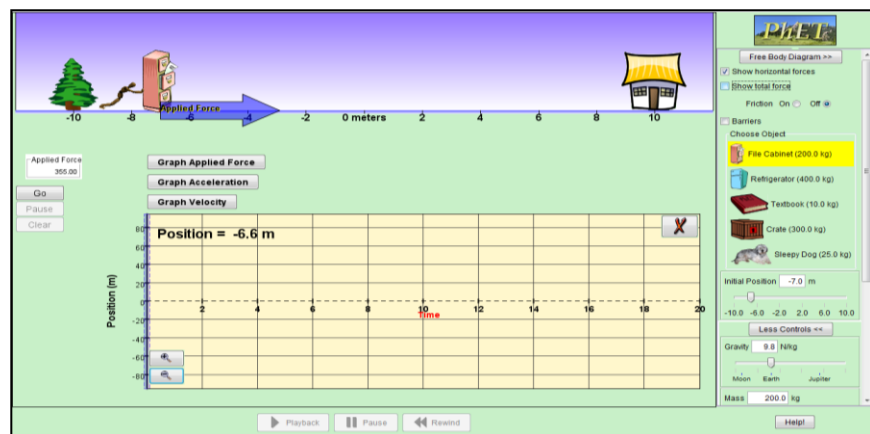
by Physics Education Technology (PhET) project. The PhET project has developed approximately 60 free downloadable physics, chemistry, and mathematics simulations that include most topics covered in a typical introductory science sequence. The selections of the computer simulations are based on the following criteria:

- a) The simulations have to be interactive, and allow the manipulation of variables that are associated with the motion of objects.
- b) All major variables associated with the motion of objects have to vary and allow students to test all their ideas.
- c) The simulations have to allow students to make observations as it runs.
- d) The presentation of the simulation should be as simple as possible, and no irrelevant distractions should be present. This is important to ensure that every input by the user will produce an easily understandable result on the screen.
- e) Graphical representations should be displaced simultaneously as the simulation runs.
- f) Special features like sound, split windows, and graphical data are expected to facilitate learning of subtopics.

Accordingly, three interactive simulations have been selected from PhET website and will be assigned to a physics class: *Force in One dimension*, *The Ramp*, and *Moving man* simulations. *Force in one dimension* will be used to explore the relationship between mass, acceleration, and force. *The Ramp* simulation presents the motion of an object in an inclined plane, which will elaborate students' understanding of Newton's second law of motion. *Moving man* simulation will provide a training opportunity for students to be familiar with the features of the other two interactive simulations before they actually use them.

For example, *The Force in One Dimension* simulation allows students to create a simple motion in one dimension, under which an object is pushed or pulled to move with a constant speed or a uniform acceleration. In a simulated real life environment, students can explore the effects of applied force on different objects such as file cabinet, refrigerator, text book, crate, or sleepy dog. It is also possible to view a free-body-diagram of all forces including gravitational and normal forces. A set of four charts show the force, position, velocity, and acceleration versus time are designed to help students construct relationships among variables. These graphs are plotted simultaneously as the simulation runs. More controls, such as gravity, coefficient of static friction, and coefficient of kinetic friction are added to allow students to understand the motion of objects in different situations.

Figure 3.2 Main window of *Force in 1D* PhET interactive simulation (www.phet.colorado.edu/idx.phy)



The above interactive simulations, in general, have the following advantages:

- a) The simulations consist of many control buttons, which allow users to input figures or drag a slider to change various variables. Students need to decide, however, which variables to vary and which to keep constant.
- b) Many controls or features can be hidden to allow more space and less distraction.

- c) If students have any difficulties, the simulation offers the *Help* option to provide assistance for troubleshooting.
- d) There are different modes for running the events: slow, medium, pause, replay, and rewind. Students can run a simulation over and over, stop a particular event and rewind it, and observe objects moving in slow motion.

Concrete objects in physics laboratory

The concrete objects and laboratory materials are selected from the many physics activities available in Grade 11 textbooks (Hirsch, Martindale, Bibla, & Stewert, C. (2002). Physics textbooks include activities that are relevant to learning key physics concepts and help student relate what they are doing to the underlying ideas. The selection of the concrete objects is based on the following criteria:

- a) The concrete objects should be simple, easy to manipulate, and commonly used in schools laboratories.
- b) Students should be able to use the apparatus to make different experimental setups to test their ideas or models.
- c) The experimental setups should allow students to make observations as it runs, as well as address safety issues such as how students will safely stop any moving object.
- d) The physical quantities such as force, mass, and acceleration should be measurable with least possible sources of errors.

Based on these criteria a set of concrete objects have been selected and will be assigned to a physics class. The concrete objects include dynamic cart, set of known masses, ticker-tape timer, banked ramp, and spring balance (Figure 3.3). These objects can take different

arrangements in which students can manipulate variables and gather data with acceptable accuracy.



Figure 3.3 Set of concrete objects used for Newton's second law activities

The concrete objects (Figure 3.3) can be designed to establish a relationship involving different variables such as net force, mass and acceleration. Figure 3.4 shows a simple setup that may allow students to recognize how an object's motion can be influenced by different variables. To do that, first of all the variables can be associated to the concrete objects, and then measured with acceptable accuracy. For example, the pulling force that is associated to the vertically hung loads (which are known masses) can be measured and varied easily. Similarly, the acceleration associated to the moving dynamic cart system can be measured by a ticker tape timer. It should also be noted that, the experimental setup in Figure 3.4 can be slightly modified to elaborate on extended types of motion such as the motion of an object in an inclined plane.

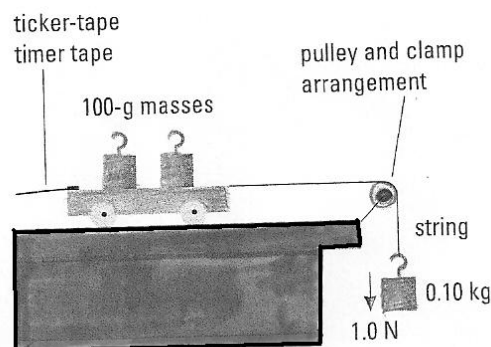


Figure 3.4 Experimental setup used to simulate the motion of a cart in a horizontal plane (Hirsch, et al., 2002)

Such manipulation of concrete objects in a physics laboratory may assist students to establish relationships between variables or test a previously formulated hypothesis. These opportunities may allow students to extend their understanding in new situations.

Student's pedagogical materials

The other learning materials that have been selected to support students in the guided inquiry process are the Student's Guide and the Grade 11 physics textbook. The homemade Student's Guide is designed to demonstrate the phases of the 5Es learning cycle. In each phase, all students are guided by a series of questions (guiding questions), demonstrations to real-life situations, and explanations to highlight the qualitative nature of force and motion with less emphasis on problem solving. Answers to the guiding questions are aimed to draw a route map for students to complete their inquiry tasks successfully. Charts and tables for data collection procedures are also included.

The physics teacher, therefore, acts as a facilitator, asking appropriate questions to guide students in their learning activities without explicitly telling them definite procedures or answers. The teacher can use the Student's Guide to evaluate students' progress and thus find the best ways to resolve any possible difficulties with aspects related to the inquiry tasks. The teacher can also use additional resources such as text book, demonstrating materials, or direct instructions to help students by asking questions, making decisions concerning how best to proceed within the investigations, and understanding how concepts are related to the driving questions.

3.4 The implementation of the teaching strategies: A lesson plan

In this study, two teaching strategies are designed to enhance the development of students' inquiry skills in two guided inquiry-based learning environments. The 5Es learning cycle is adopted to mirror the features of the guided-inquiry learning.

This section describes the implementation of the teaching strategies in computer-based simulation and physics laboratory environments. Both strategies use the 5Es learning cycle in a similar way except in the dimension of the utilization of the assigned learning tool.

Before engaging students in the 5Es cycle, the teacher will take the first day to organize students in small groups and train them with their assigned learning tool. A group assigned to the PhET interactive simulations is expected to use *the moving man* simulation to be familiar with the general features and functions of PhET simulations. Another class will be assigned to concrete objects to practice how to measure physical quantities associated with the natural phenomena such as time, speed, acceleration, and net force.

The training session, in both classes, is designed in form of learning activities, so students can monitor their progression and practice their abilities within a learning context (see Student's Guide – Appendices IV and V). During the phases of 5Es cycle, both classes will have identical instructional materials and inquiry tasks, but they will be assigned different learning tools. The questions presented at the end of each learning segment of the 5Es cycle are designed to *evaluate* students' progress.

Learning in the computer-based simulation environment

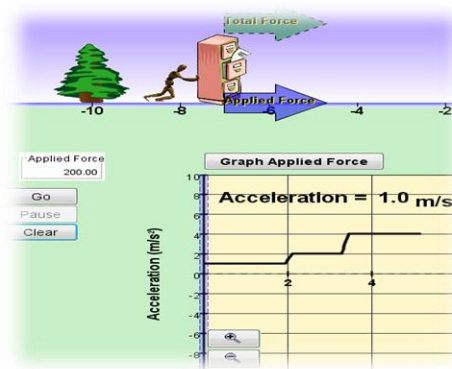
To *the engage* students in the first phase of the 5Es learning cycle, the teacher would present a short story-telling. The story-telling describes a very common scenario of a man, Christopher, who went snow sledding on a windy day on the Rideau Canal. The students are expected to respond to questions related to the story. Posing a question such as “How come! In spite of steady wind, Christopher was sledding faster and faster” (Students' Guide, Appendix D, p.123) aims to recall the students preexisting knowledge and ideas about the influence of force (the blow of winds) on the motion of objects (sledding on ice).

The teacher in this phase cannot provide definite answers to students even if they insist on explanations or clarifications. However, at the end of the *engage* phase, the teacher can use different resources (textbook, demonstration tools, or hints) to elicit students' responses, and thus resolve any inconsistencies as a way of recognizing the basic concepts of force and motion.

Students in simulation group are expected to work in 2-member groups and begin their *explore* phase by completing a worksheet that guides them towards a sequence of tasks. First, the students will be presented with a real-life situation, to describe what possible scenarios that might happen. Second, the teacher is expected to encourage students to predict relationships between variables such as force and change in motion (acceleration). Then, the teacher would guide students to design procedures to test their predictions.

Force in one dimension simulation can be used to test students' predictions by making cause and effect relations. The simulation contains controls that allow students to create objects with which they can associate net force, mass, and acceleration as variables. For example, students can use the controls in the simulation to change the applied force on an object and observe its acceleration when the mass is kept constant.

Figure 3.5 A partial snapshot from the *Force in 1D* simulation



The graphical representation option (Figure 3.5) will show the trend of the resulting type of motion in each attempt. Finally, before students conclude the result and compare it with the

prediction they have made earlier, the teacher should introduce appropriate terminologies to describe variables such as independent variables, control variables, and dependent variables.

Next, students are expected to work in 4-member groups to present their own explanations that make sense of their observational data, and establish relationships between net force, mass, and acceleration to state Newton's 2nd law of motion in words and symbols.

In the *explain* phase, the teacher may ask students to write two statements regarding the relationships between force and acceleration, and acceleration and mass. To help students construct their statements, the teacher engages them in scaffolded learning events. The events should give explanations to what students have observed during the *explore* phase and introduce students to situations to be modeled in order to relate net force, acceleration, and mass.

The teacher in these events guides students through transitioning tasks that conclude with introducing students to scientific terminologies to state Newton's second law of motion. In the transitioning tasks, students may visit their data collection part and their personal observations over and over, looking for evidence to connect the trends of their graphs with their current learning tasks. Small-group and whole-class discussions follow that focus students on the conclusions they will make to reach a consensus about the relationships between net force, acceleration, and mass.

Finally, in the *elaborate* phase, students are expected to extend their understanding and apply Newton's 2nd law of motion in new situations. Students are expected to go back to their previous group setting (2-member groups) to begin a new investigation to describe the acceleration of an object moving in an inclined plane.

The computer simulation is assigned to help students make qualitative models of the factors affecting the acceleration. *The ramp* simulation (Figure 3.6) can be used to define

relations between different variables (mass, friction, and ramp angle) to show how they are influencing the motion of an object.

For example, to test the influence of the slope of the inclined plane on the acceleration of object, the ramp angle slider is provided by the simulation so students can visualize the responding types of motion as the slope of the ramp changes.

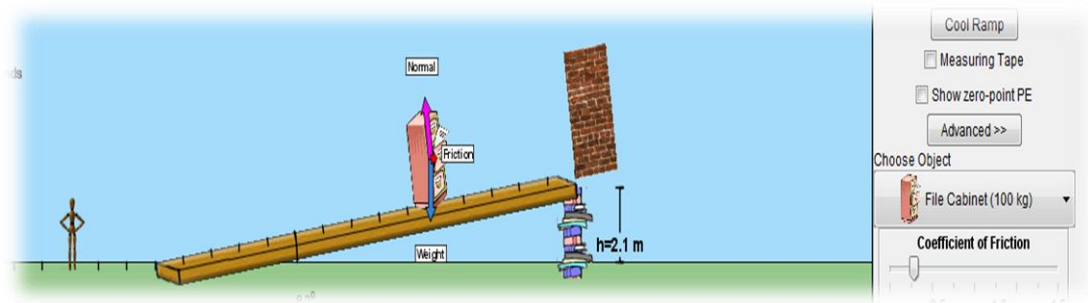


Figure3.6 A partial snapshot from *The Ramp* simulation

In summary, students are expected to learn with the computer simulation to progress through the 5Es learning cycle. The students may use the interactive simulations at all times, but the intensive use of the simulations will be in the *explore* and the *elaborate* phases.

Learning in the physics laboratory environment

Students in the physics laboratory can begin their *engagement* phase in a similar way as the students in simulation group. First, the teacher can present the same story that describes Christopher's experience with snow sledding on the Rideau Canal. Then students are expected to respond to the questions related to the story to recall their preexisting knowledge about the influence of force on the motion of objects.

In the *explore* phase, students are expected to work in 2-member groups and begin this phase by completing a worksheet to describe their procedures and write conclusions using their own words. The worksheet consists of the same inquiry tasks as in the simulation group. The

objectives of the tasks are centered to encourage students to make predictions about real-life scenarios and design procedures to test them.

Students can use the assigned concrete objects to test their predictions. Figure 3.7 shows a setup in which a known mass is hung vertically to pull the dynamic cart. Students are expected to use this setup to determine the influence of the vertical mass (pulling force) and the mass of the system on the resulting type of acceleration.

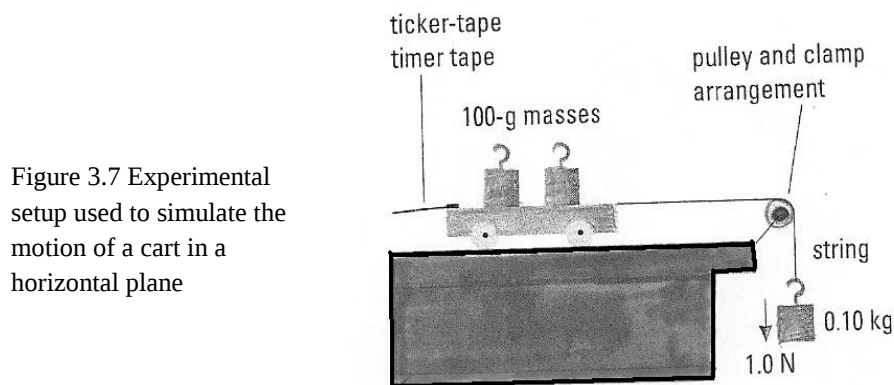


Figure 3.7 Experimental setup used to simulate the motion of a cart in a horizontal plane

The teacher's role is to assist students to overcome the technical difficulties, and to guides them to carry out any necessary calculations before reflecting their data in graphical representation.

Next, students are expected to work in 4-member groups to analyze the data they have gathered and *explain* the events they have observed during their exploration phase. To make it effective, students can visit their experimental setup or their personal observations in a back-and-forth manner looking for evidence to support their explanations. Whole-class discussions follow that help students to conclude the relationships between net force, acceleration, and mass.

Meanwhile, the teacher is expected to guide students through the same scaffolded learning events that the teacher would have used with students in the simulation group (described

on page 37). The teacher guidance is expected to introduce new scientific terminologies to help students state Newton's second law of motion in words.

Finally, in the *elaborate* phase, students are expected to extend their understanding and apply Newton's 2nd law of motion in the same situations presented in the computer simulation environment. In two-member group settings, students are expected to describe the acceleration of an object moving on an inclined plane, and to examine the influence of the mass and the ramp angle on the object's motion.

Students may use the concrete objects to construct an inclined ramp (Figure 3.8), and observe the motion of a dynamic cart at different ramp angles. Additional known masses can be provided to examine the influence of mass (if any) on the acceleration of the object as it is sliding down the ramp.

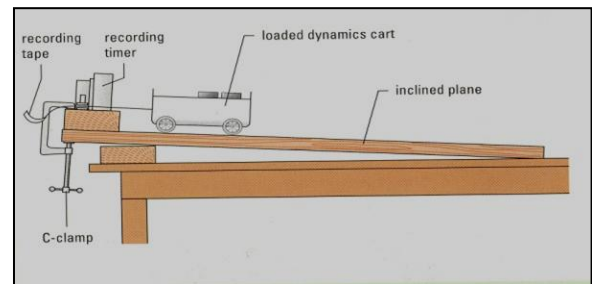


Figure 3.8 Experimental setup to simulate the motion of a cart in an inclined plane

This investigation seems complex, therefore, the teacher can guide students by validating students' models, asking questions, facilitating collaboration between students, giving hints or methods such as drawing free-body diagram.

Prior to describing the actual implementation of the teaching strategy in a classroom, a lesson plan of Newton's second law activities is given in Table 3.1.

Table 3.1 Lesson Plan

5Es [*] phases	Objectives Students are expected to:	Inquiry task	Inquiry skills involved	Role of learning tool	
				Concrete objects	Computer simulation
Engage [*]	recall the influence of forces on objects' motion	Reading a story-telling and respond to the associated questions. Posing questions to be investigated in the next phase.	Identifying suitable definitions for the variables	Students will not use their learning tools	Students will not use their learning tools
Explore [*]	perform an experiment leading to establish Newton's 2 nd law of motion	Designing and conducting an inquiry into the relationship between the acceleration of an object and its net force and mass.	Selecting a testable hypothesis. Designing and testing an investigation. Identifying the manipulated, responding and controlled variables. Obtaining data and identifying graph that represents the data.	Provide concrete subjects to manipulate. Allow students to observe the motion of real objects.	Provide controls that allow students to create objects with which they can associate net force, mass, and acceleration as variables. Allow students to change variables and control others. Show the trend of the resulting type of motion in forms of graphical representations.
Explain [*]	state Newton's 2 nd law in words and symbol	Analyzing the relationships between acceleration and applied forces.	Describing the relationship between the variables.	The concrete objects will be used to confirm students' explanations.	The simulation will be used to confirm students' explanations.
Elaborate [*]	apply Newton's 2 nd law of motion in new situations: motion of an object in an inclined plane	Conduct an inquiry that applies Newton's laws to analyze, in qualitative terms, the forces acting on an object, and use free-body diagrams to determine the net force and the acceleration of the object.	Designing and testing an investigation.	Allow students to create different setups to test the motion of an object in a rough inclined plane. Observe the motion of real objects in an inclined plane.	Allow students to test the motion of an object in a rough and frictionless inclined plane. Show free body diagrams.
<i>E v a l u a t e[*]</i>					

*Renner, 1985

3.5 The actual implementation of the teaching strategies in the classroom

The research proposal was approved by the Ottawa-Carleton Research Advisory Committee for implementation in semester (I), 2010. A physics teacher, then, was invited to volunteer in this project. He agreed to implement the teaching strategies in two of his grade 11 physics classes at the time when Newton's second law was taught.

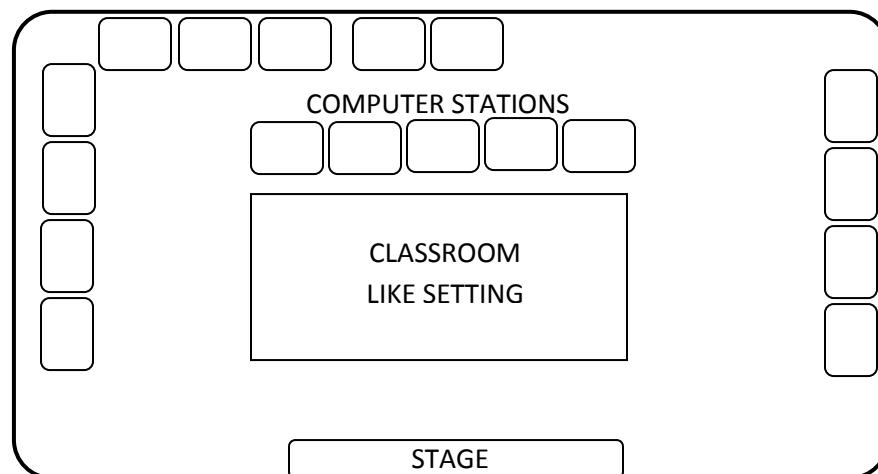
54 students from two naturally formed settings participated in this project: 26 students (8 girls and 18 boys) from one class and 28 students (16 girls and 12 boys) from another class. Before the beginning of Newton's second law activities, there was a meeting with the physics teacher to listen to his feedback on the scenario of the learning events.

The subsequent parts describe the learning environments and the conditions at the time of implementation, as well as remarks on what went wrong and what went right in both classes (Tables 3.2 and 3.3).

Computer simulation group

A class of 28 students (16 girls and 12 boys) was assigned to a set of interactive computer simulations to conduct Newton's second law activities in the computer lab.

Figure 3.9 Illustration of the learning environment (Computer Lab)



The computer lab consisted of two major parts: computer stations, and desks facing the stage (Figure 3.9). All computers were IBM desk-top machines and were connected to the internet by a wireless modem. Students' desks were used for taking notes from the board, class discussions, or demonstration purposes.

Table 3.2 Breakdown of the learning events in the computer simulation group

Event	Duration *	Remarks
Training session	30 min.	Students explored the features of the simulation in two-member collaborative groups. Despite the slow starting of the training session, students continued smoothly and completed the training with no major difficulties.
5Es – <i>Engage</i>	15 min.	It was a very short phase, during which students recalled their preexisting knowledge of force and motion. There was a discussion in the last 5 minutes to <i>evaluate</i> students' responses and determine questions to be explored in the next phase.
5Es – <i>Explore</i>	80 min.	Using 2-member group settings, students performed the activities in their own pace. Generally, students learned with the computer simulation with little assistance from the physics teacher. The questions at the end of this learning segment were used to <i>evaluate</i> students' performance.
5Es – <i>Explain</i>	30 min.	Students shared their results in 4-member groups, and later with the physics teacher. The physics teacher, in turn, introduced new terminologies to use and clarified the expressions for directly proportional and inversely proportional relationships. Eventually, the class state Newton's second law in words and symbols.
5Es – <i>Elaborate</i>	30 min.	In the final phase, students elaborated their understanding of Newton's second law in new situations. They relied on their newly acquired understanding to respond to the posed questions rather than on the computer simulation. Thus, some questions could not be answered correctly.

*The time indicated is an approximate time.

**The average number of attendance is 26 students.

***3 physics periods were needed to complete the learning events.

Physics laboratory group

A class of 26 students (8 girls and 18 boys) was assigned to a set of concrete objects to conduct Newton's second law activities in the physics laboratory. The physics laboratory (which was also their class) consisted of 9 benches facing the stage (Figure 3.10). Students used these benches to assemble experimental setups, hold class discussions, or take notes from the board.

Figure 3.10 Illustration of the learning environment (Physics Lab)

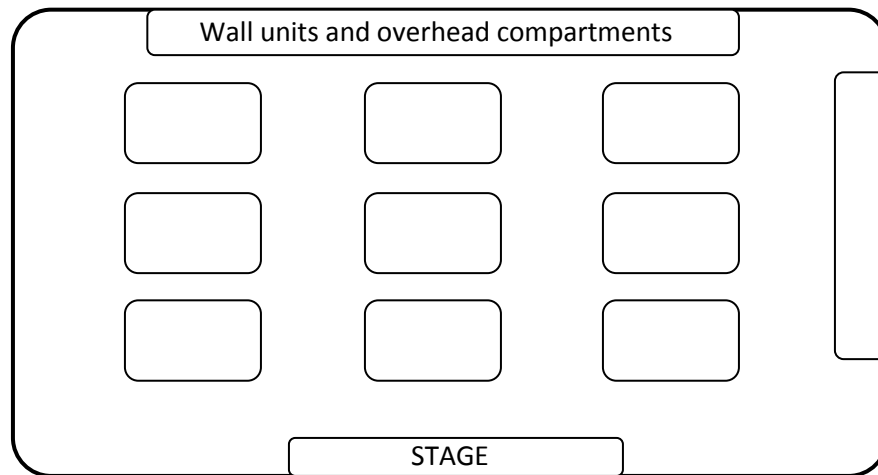


Table 3.3. Breakdown of the learning events in the laboratory group

Event	Duration *	Remarks
Training session	50 min.	Students explored the apparatus and performed an activity about measuring average velocity and acceleration using tickertape timer. Students were very active during their training.
5Es – <i>Engage</i>	15 min.	It was very short phase, during which students recalled their preexisting knowledge of force and motion. There was a discussion in the last 5 minutes to the <i>evaluate</i> students' responses to determine the questions to be explored in the next phase.
5Es – <i>Explore</i>	170 min.	Using 2-member group settings, students experienced real natural phenomena. This feeling decreased with time. Students were involved in technical difficulties regarding the setup of the experiment, and later in mathematical calculations. Students could not be weaned away from the physics teacher's assistance. The questions at the end of this learning segment were used to <i>evaluate</i> students' performance.
5Es – <i>Explain</i>	40 min.	Students have shared their results in 4-member groups, and later with the physics teacher. The physics teacher introduced new terminologies to use, and clarified the expression for directly proportional and inversely proportional relationships. Eventually, the class state Newton's second law in words and symbols.
5Es – <i>Elaborate</i>	40 min.	In the final phase, most of the students had developed feelings of frustration. Some students showed low interest to elaborate the concepts of Newton's second law in new situations; and many others completed their task without using the concrete objects.

*The time is an approximate time.

**The average number of attendance is 24 students.

***5 physics periods were needed to complete the learning events.

To conclude, it seems likely that on the basis of the ideal plan, both strategies have been reasonably implemented. Students from both learning environments have fairly followed the instructions given to them by the teacher, or stated in their guides. The physics teacher was aware of his role to provide the necessary time and materials, and guide students through the inquiry tasks and phases. Apart from the technical difficulties experienced in the physics laboratory and the unexpected time delay, students were able to proceed through the activities and accomplished their inquiry tasks.

Nevertheless, the implementation of the teaching strategies in classrooms does not tell which strategy is more effective. The following chapters therefore will discuss the methods and procedures taken to determine the effectiveness of the teaching strategies as a whole, and the assigned learning tools, in specific, on the development of students' inquiry skills.

Chapter 4: Methodology

The methodology chapter begins with a brief description of the research strategy (Section 4.1) which includes the statement of the research questions and the hypotheses. Then an overview is given to discuss why a quantitative approach was selected to lead the research inquiry.

Further clarifications are presented in Section 4.2 to describe the methods taken to select the participants and the conditions assigned to the learning environments.

Prior to presenting the research design and data analysis procedures is section 4.3, the instruments used to measure the dependent variable are diagnosed and analyzed to emphasize their reliability and validity.

Finally, Section 4.4 identifies the sources of threats and determines the necessary precautions needed to maintain the validity of the research design.

4.1 Research strategy

The overall goal of this study is to compare the effectiveness of the visualization via interactive computer simulation and the manipulation of concrete objects in a physics laboratory on the development of students' inquiry skills. The learning activities have been developed to help students in establishing relationship between force, mass, and acceleration, and developing scientifically acceptable explanations to express Newton's 2nd law of motion.

Our basic research questions are:

1. What are the possible impacts of the visualization of Newton's second law of motion via interactive computer simulation on the development of students' inquiry skills?
2. What are the possible impacts of the manipulation of concrete objects to perform Newton's second law experiment on the development of students' inquiry skills?

3. How are the effects of the utilization of interactive computer simulation and the manipulation of concrete objects compared?

Accordingly the following hypotheses are postulated and will be computed at the 0.05 level of significance:

Hypothesis 1: students taught via inquiry-based computer simulation will significantly develop their inquiry skills better than students taught via inquiry-based laboratory.

Hypothesis 2: students taught via inquiry-based laboratory will significantly develop their inquiry skills better than students taught via inquiry-based computer simulation.

Hypothesis 3: students taught via inquiry-based laboratory and inquiry-based computer simulation will significantly develop their inquiry skills.

These research questions are straightforward to answer with a simple study. The ideal study would be to compare, in a quantitative method, the development of students' inquiry skills in two learning environments: one with an interactive computer-based simulation, and the other with concrete objects and materials in a physics laboratory.

Quantitative method

The quantitative approach involves testing "objective theories" by examining the relationship among factors or variables. These variables can be measured typically on instruments, so that numbered data can be analyzed using statistical procedures. Researchers who engage in this form of inquiry have assumptions about testing theories deductively, building in protections against bias, controlling for alternative explanations, and being able to generalize and replicate the findings (Creswell, 2009).

The quantitative approach is associated with two important components: philosophical assumptions or worldview, and distinct procedures (Creswell, 2009). To plan for a study, researchers need to think through the philosophical worldview that they bring to the study, the strategy of inquiry that is related to this worldview, and the specific research design that implements the strategy of inquiry into practice (Creswell, 2009).

This attempts to test and compare the effects of two learning tools (or mind-tools) in a guided inquiry environment on the development of student's inquiry skills. Thus, developing numeric measures of observations to determine the causes and effects becomes a paramount goal. This view holds a deterministic philosophy in which causes determine effects of outcomes, and the problem reflects the need to identify and assess the causes that influence outcomes.

On the basis of the above framework, the research method will be designed from the postpositivist perspective to determine whether the learning tools influence students' abilities to develop their inquiry skills, and if so, which influence is more significant.

4.2 Research method and data collection

Participants

The participants will be conveniently selected from a high school in Ottawa, in two naturally formed settings. The participants' natural setting is grade 11 – university preparation section. It will be beneficial to observe how students of grade 11 can establish relationships between force, mass, and acceleration; and state Newton's second law of motion in their first attempt to understand it. With this convenience sampling, not every grade 11 student in Ottawa has an equal probability for being selected. Therefore, the procedure is classified as a quasi-experimental design.

In a quasi-experiment, the number of participants (sample size) is a critical element to maintain the sensitivity of the design in detecting real differences between or within the groups. Three parameters, alpha – level, the power, and the effect size control the sample size required. The value of the effect size can be adopted from similar previous studies. Wu (2006) investigated how sixth graders develop inquiry skills to construct explanations in an inquiry-based learning environment. The data from Wu (2006) suggests the between-group effect size (f) should be 0.49. Hence, the effect size parameter (φ) can be determined by:

$$\varphi = f \sqrt{n}$$

Where n is the number of subjects per group.

Accordingly, the Pearson-Hartley Power Chart (Maxwell, 2004, p. A27) suggests that the within-subject degree of freedom (df_{denom}) is equal to 60 under the following conditions:

- The power = 0.95
- Alpha – level (α) = 0.05
- The effect size parameter (φ) = 2.64
- The between-subject degree of freedom (df_{num}) = 1, ($df_{\text{num}} = a - 1$, where a is the number of groups)

Therefore, for two groups and df_{denom} equals to 60, the sample size should equal to 54 subjects which is approximately the same sample size as in Wu (2006) study.

Data collection procedures

In this section, we will describe the factors or conditions of the study, and how these conditions will be assigned to the subjects. We will also specify the variables in the experiment and discuss how they are going to be measured.

Without disturbing the school academic plan, this study has been conducted during the first semester of school academic year 2010 – 2011. The content of the study is the regular physics course for grade 11 – university preparation section, developed by Ontario Ministry of Education, and will be facilitated by a high school physics teacher. The participating students will come from two naturally formed classrooms (each of approximately 27 students). Both groups will conduct “Force in one dimension”, one of the experiments in Ontario Curriculum – Physics (2009). One group will be randomly assigned to a computer-based environment, and the other one to a physics laboratory environment.

Participants from both groups will be requested to attend five events at their own school facilities. They will be asked to:

1. answer paper-and-pencil Test of Integrated Process Skills (TIPS II);
2. take the Mechanics Diagnostic Test (MDT) of conceptual understanding;
3. attend a training session;
4. perform Newton’s second law activities;
5. answer paper-and-pencil post-TIPS II.

The pre- and post-TIPS II scores are expected to indicate the prior level of students’ skills and measure any development in their inquiry skills that may occur during Newton’s second law activities (Burns, Okey, & Wise, 1985). A number of multiple choice questions are generated to test five components of inquiry skills. Following is a list of these inquiry skills along with sample items (TIPS II, Appendix C):

Inquiry skill (1): identifying suitable definitions for the variables.

Sample test item: *An auto manufacturer wants to make cars cheaper to operate. They are studying variables that may affect the number of miles per gallon that autos get.*

Which variable is likely to affect the number of miles per gallon?

- A) Weight of the car.*
- B) Size of the motor.*
- C) Color of the car.*
- D) Both A and B.*

Inquiry skill (2): identifying the manipulated, responding, and controlled variables.

Sample test item: *Marie wondered if the earth and oceans are heated equally by sunlight. She decided to conduct an investigation. She filled a bucket with dirt and another bucket of the same size with water. She placed them so each bucket received the same amount of sunlight. The temperature in each was measured every hour from 8:00 a.m. to 6:00 p.m. Which of these variables is controlled in Marie's study?*

- A) Kind of water placed in the bucket.*
- B) Temperature of the water and soil.*
- C) Type of material placed in the buckets.*
- D) Amount of time each bucket is in the sun.*

Inquiry skill (3): selecting a testable hypothesis.

Sample test item: *A class is studying the speed of objects as they fall to the earth. They design an investigation where bags of gravel weighing different amounts will be dropped from the same height. In their investigation which of the following is the hypothesis they would test about the speed of objects falling to earth?*

- A) An object will fall faster when it is dropped further.*

B) *The higher an object is in the air the faster it will fall.*

C) *The larger the pieces of gravel in a bag the faster it will fall.*

D) *The heavier an object the faster it will fall to the ground.*

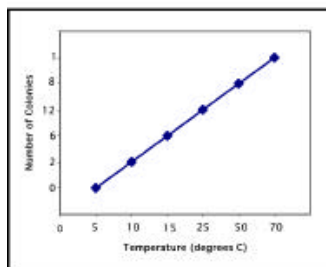
Inquiry skill (4): obtaining data, identifying a graph that represents the data, and describing the relationship between the variables.

Sample test item: *A student in a science class studied the effect of temperature on the growth of bacteria. The student obtained the following data:*

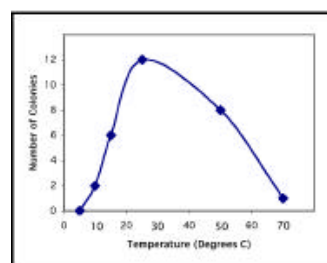
<i>Temperature of the growth chamber (°C)</i>	<i>Number of bacterial colonies</i>
5	0
10	2
15	6
25	12
50	8
70	1

Which graph correctly represents the data from the experiment?

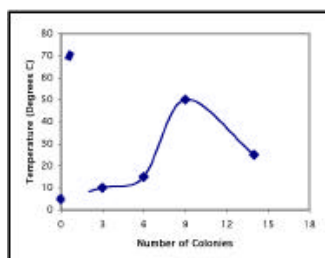
A)



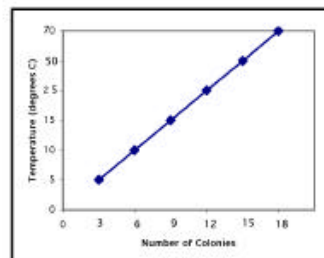
B)



C)



D)



Inquiry skill (5): designing and testing an investigation.

Sample test item: *Jim thinks that the more air pressure in a basketball, the higher it will bounce.*

To investigate this hypothesis he collects several basketballs and an air pump with a pressure gauge. How should Jim test his hypothesis?

A) Bounce basketballs with different amounts of force from the same height.

B) Bounce basketballs having different air pressures from the same height.

C) Bounce basketballs having the same air pressure at different angles from the floor.

D) Bounce basketballs having the same amount of air pressure from different heights.

The TIPS (II) is not specific to a given curriculum or content area, it may be used across various levels and disciplines of science (Wu & Hsieh, 2006). For validation purposes, the test (36 questions) was piloted and administered to 162 students in grades 7 – 12 from the southeastern area of the United States. Pupils in the sample populations were allotted a normal class period to complete the test. Typically, the high school age students require 25 to 35 minutes to finish the test. Results yielded a mean score of 19.14 and a total test reliability of 0.86. Mean difficulty and discrimination indices were 0.53 and 0.35, respectively (Burns, 1985; Monica, 2005).

Students will also answer a questionnaire in conceptual understanding in mechanics namely Mechanics Diagnostic Test, MDT (Halloun, 1985). The MDT (36 questions) is designed to assess the students' basic knowledge of mechanics. The questions are selected to assess the students' qualitative conceptions of motion and its causes. A student's score on the diagnostic test is a measure of his/her qualitative understanding of mechanics. For validation purposes, the test was piloted and administered to 49 high school students. Results yielded a mean score of 10.96 (30%) and a total test reliability of 0.86 (Halloun, 1985).

For the purpose of this study, the subject teacher will choose 20 relevant items of the questionnaire to be administered. The selected questions from MDT will approximately take 20 minutes to complete. Students' responses to the MDT questionnaire will be used to help the teacher divide students in to small discussion groups (see Student's Guide). Every two students with close level of conceptual understanding in mechanics will be grouped together (homogeneity grouping).

On the other hand, students' answers to the MDT questionnaire will be used to detect any preexisting differences between the two classes in the conceptual understanding in mechanics. Therefore, the MDT questionnaire can be analyzed as a covariate factor to normalize such differences, if any, and prevent any correlations that may influence students' scores of pre- and post-TIPS (II) (the dependent variable).

4.3 Research design and data analysis procedures

Research design

A two-way split-plot design will be performed to examine if there is a significant statistical difference between the means of students' scores in the pre- and post-TIPS (II). The number of questions answered correctly in the TIPS (II) will serve as the dependent variable in a 2 Learning Tool $\times$ 2 Time split-plot Analysis of Variance (ANOVA). The Learning Tool factor (between-subjects) will have two levels: interactive computer simulation and a physics laboratory; and the Time of test factor (within-subjects) will have two levels: pre- and post-Newton's second law activities. Table 4.1 describes the two factors and their levels.

Additionally, a one-way ANOVA comparing the MDT scores of participants in the two Learning Tools conditions will be conducted to ensure no pre-existing differences in conceptual understanding.

Table 4.1 Two-way split plot design

Factor A: learning tool (Between)	Factor B: Time of test (Within)	
Physics laboratory	Pre-	Post-
Computer simulation	Pre-	Post-

Data analysis procedures

The data will be compiled and analyzed using SPSS data processing software. Alpha level will be set at 0.05 of significance. Initially, we will specifically be looking at the Learning Tool $\times$ Time of test interaction effect, which indicates whether, or not, the means of students' scores in the TIPS (II) depend on the type of Learning Tool. If the two-way interaction effect is significant, the follow up test will be the simple effect of Time of the TIPS (II) (pre- and post-) within the computer simulation level, and simple effect of Time of the tests within the physics laboratory level. These tests will determine any influence of one of the Learning Tools on the development of students' inquiry skills (*Hypotheses 1 and 2*).

Two pairwise comparisons will be useful to perform in order to elaborate on the follow up tests. The first test is a pairwise comparison between the post TIPS (II) of the computer simulation and physics laboratory groups. The second one is a pairwise comparison between pre-TIPS (II) of computer simulation and physics laboratory groups.

In case the two-way interaction effect is not significant, the follow up test will be the main effect of Learning Tool factor and the Time of test factor (*Hypothesis 3*).

Finally, in order to validate the research design and make sure it will be implemented as planned, it is very important to look for the potential sources of violation, and avoid them by applying specific measurements and precautions.

4.4 Validity of the Design

The validity is known as the correspondence between a proposition describing how things are planned and how they really work. Experimental researchers need to identify potential threats to the validity of their experiments and design them so that these threats will less likely arise or they are minimized. There are three potential threats to the validity of the research design: statistical conclusion, internal, and external threats.

Statistical conclusion validity

Statistical conclusion validity emphasizes whether the statistical inferences are correct or not. One way in which a study might be an insecure base is when the statistical hypothesis cannot be tested. The way to release this threat is to increase the power. We need to design an experiment with procedures that are very sensitive to detect any effect or relationship between the dependent variable and the independent variable. There are three factors that may affect the value of the power: sample size, unreliable dependent variable, and high variability.

In this study, the procedures are designed in a way to detect any relationship between students' scores in the skill TIPS (II) and the kind of learning tool they are using. Additional measures have been taken care to maintain the sensitivity of the design and hence the level of power. First, the sample size is calculated so that the power levels at 0.95 and alpha value equals 0.05. Second, to avoid the effect of unreliable scores of the skill test (dependent variable) in reducing the power, the test is made up of 36 items (questions) and can be performed in 30 – 40 minutes. Therefore, students will less likely be able to pass the test by just guessing. Research findings suggest that the longer the pre- or post-TIPS (II), the less likely the test scores will vary due to random errors. Third, the skills test (TIPS II) will be used exclusively as the pre- and post-test in order to eliminate using the same test multiple times for the same statistical hypothesis.

Internal Validity

The internal validity is known as the third variable problem. A crucial factor or factors may appear to threaten the relationship between the dependent and independent variables. There might be another unseen variable responsible for apparent relationship or lack of relationship between variables. In this study, unseen factors, such as quality of teaching, gender, or motivation, could be affecting students' scores of the skills test (the dependent variable) instead of the learning tool (the independent variable). Other threats to internal validity are also possible, such as the missing of data for one or more time periods (attrition), regression, and maturation.

Several measures have been considered to reduce these threats. First, the learning environment, for the control and treatment groups, is set to be identical, except in the type of learning tool used. Students will have the same teacher, teaching strategy, kind of group setting, and preparation sessions.

External Validity

This validity regards the possibility to generalize the findings to the entire population, time, and setting. The central concern in this issue is whether or not the sample subject is actually representing the entire population. Many times the effect of observed treatment in a particular study cannot be generalized for the entire population, due to lack of consistency.

A partial solution to this problem is to assure that the study uses a heterogeneous group of subjects, times, and setting. Note that a great diversity group may threaten the statistical conclusion validity. Therefore, we should be very careful when analyzing the research outcomes. With a homogenous sample of subjects it is easy to achieve a statistical significant and often detrimental to the generality of the findings. With a heterogeneous sample of subjects it becomes more difficult to obtain statistically significant findings, but allows generalization of these

findings with greater confidence to other situations. This dilemma makes us to rest on the ideas of what is theoretically important about the findings.

Chapter 5: Results

This chapter presents and interprets the results of the study. The statistical procedures outlined in section 4.2 are used for data analysis. The results are presented in the following order.

Section 5.1 presents descriptive statistics to the scores obtained in MDT, the pre-TIPS, and the post TIPS tests. The students' scores will be represented in various types of graphical representations so to look for the general trends and the extreme distributions.

Section 5.2 presents the statistical results obtained from the SPSS output data sheets. The SPSS output will be used to support or reject the hypotheses of the study. Further interpretations to the inferential statistics will be given to highlight any significant findings.

5.1 Descriptive statistics

Students' scores of the pre- and post-skills test (Table 5.1) were used to determine the impacts of the visualization via interactive computer simulation and the manipulation of concrete objects in a physics laboratory on the development of students' inquiry skills. But before doing that, the results from the test of conceptual understanding (MDT) would be analyzed in order to waive any possible influence of students' conceptual understanding in mechanics on their performance in the pre- and post-skills test.

Table 5.1 Students' scores in MDT, pre-TIPS, and post TIPS

Laboratory group				Computer simulation group			
Students	MDT**	Pre-TIPS (II)***	Post TIPS (II)	Students	MDT	Pre-TIPS (II)	Post TIPS (II)
A1	14	24	21	B1	12	27	31
A2	13	31	32	B2	10	24	22
A3	12	34	36	B3	12	28	29
A4	14	31	34	B4	10	24	31
A5	15	28	30	B5	13	35	35
A6	13*	33*	Absent	B6	13	27	30
A7	15	33	34	B7	11	30	34
A8	9	34	35	B8	Absent	Absent	16*
A9	14	31	33	B9	12	27	27
A10	12	32	32	B10	5*	28*	Absent
A11	8	28	30	B11	7	34	32
A12	5	33	31	B12	10	30	30
A13	12	27	31	B13	9	32	30
A14	6	22	26	B14	10	28	26
A15	14	23	26	B15	10	25	25
A16	10	34	33	B16	12	24	25
A17	12	29	30	B17	10	20	24
A18	11	25	22	B18	13	30	33
A19	14	31	31	B19	10	33	34
A20	14*	36*	Absent	B20	10	25	34
A21	14	29	30	B21	14	31	33
A22	12	32	34	B22	12*	32*	Absent
A23	8	32	34	B23	14	29	32
A24	8	34	34	B24	12	33	34
A25	13	22	29	B25	8	24	26
A26	11	28	26	B26	14	25	29
				B27	7	31	33
				B28	15	25	32

*These scores were not used in the data analysis.

**The maximum score of MDT is 20.

***The maximum score of TIPS is 36.

Test of students' conceptual understanding in mechanics

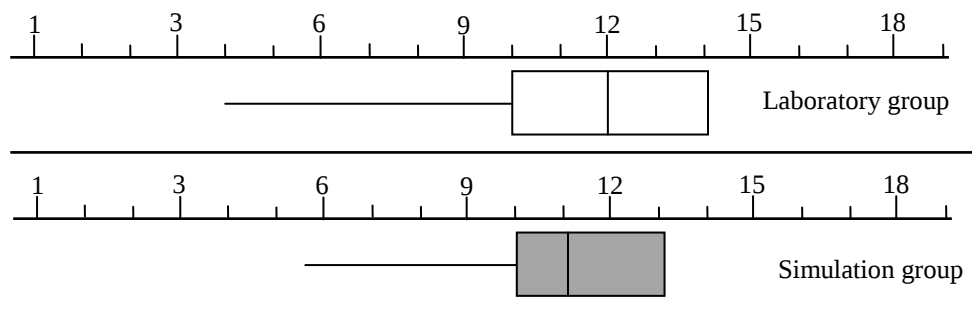
Scores from 49 students involved in the study were used to analyze the results of the Mechanics Diagnostic Test (MDT). The descriptive results of the MDT showed some evidences that students from both groups might have similar levels of conceptual understanding in mechanics. First, the means and standard deviation values of the MDT scores were consistent across the groups (Table 5.2).

Table 5.2 MDT results by group

Group	N	Mean	Std. Deviation
Laboratory	24	11.50	2.844
Interactive simulation	25	11.12	2.166
Total	49	11.31	2.502

Second, the scores of the majority of students in the laboratory group ranged from 10 to 14, which were similar to that of the majority of students in the simulation group (Figure 5.1). Finally, the Box-plot (Figure 5.1) also showed similar trends of extreme scores as indicated by the substantial extension of the whiskers on the left hand side.

Figure 5.1
Box-plot for pre-
and post-TIPS by
group



In conclusion, it seemed that the descriptive results of the MDT suggested that the overall levels of students' conceptual understanding in mechanics have reasonably similar distributions (Figure 5.2).

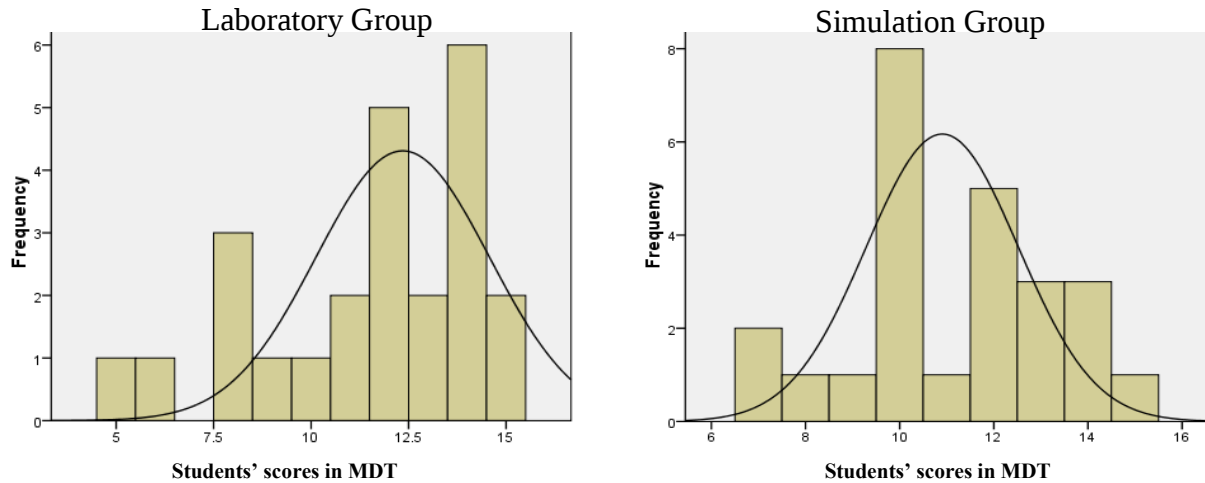


Figure 5.2 Histogram plots ranges of students' scores in MDT vs the frequency

Pre- and post-inquiry skills test scores

Scores from 49 students were used to analyze the results of the pre- and post-test of inquiry skills (TIPS II). In fact, the pre- and post-TIPS (II) were expected to measure the levels of student's inquiry skills before and after conducting Newton's second law activities, respectively. The pre- and post-TIPS scores could be compared to assess the development of students' inquiry skills that might occur during the learning activities (Burns, 1985, Monica, 2005).

The first thing that should be noticed from Table 5.3 is the mean of TIPS scores. In average, the means were higher (by 10 points) than the mean score reported by Burns (1985) for grade 11 students.

Table 5.3 Pre- and post-TIPS results by group

	Pre-TIPS (II)		Post TIPS (II)	
	Laboratory	Computer Simulation	Laboratory	Computer Simulation
Mean	29.46	28.04	30.58	30.04
Standard Deviation	3.912	3.813	3.933	3.668
N	24	25	24	25

Second, Tables 5.5 and 5.6 show that 17 students from computer simulation group (N=25) scored higher in the post TIPS than in the pre-TIPS, versus 16 from laboratory group (N=24). Third, the majority of students from both groups scored 1 to 3 points higher in the post TIPS than in the pre-TIPS (Table 5.3). Nevertheless, around one-fifth ($\frac{1}{5}$) of students from both conditions have shown negative gain in their post skills test (Table 5.5). This similarity between both conditions may conclude that, the utilization of the assigned learning tools during Newton's second law activities lead to overall similar gain in the TIPS tests.

Table 5.4 Positive gain in the post skills test

Gain in the post skills scores*	Number of students	
	Simulation group	Laboratory group
1 – 3	10	13
4 – 6	4	2
7 – 9	3	1
Total	17	16

*The Gain was obtained by subtracting the post skills test scores from the pre-skills test scores.

Table 5.5 Negative gain in the post skills test

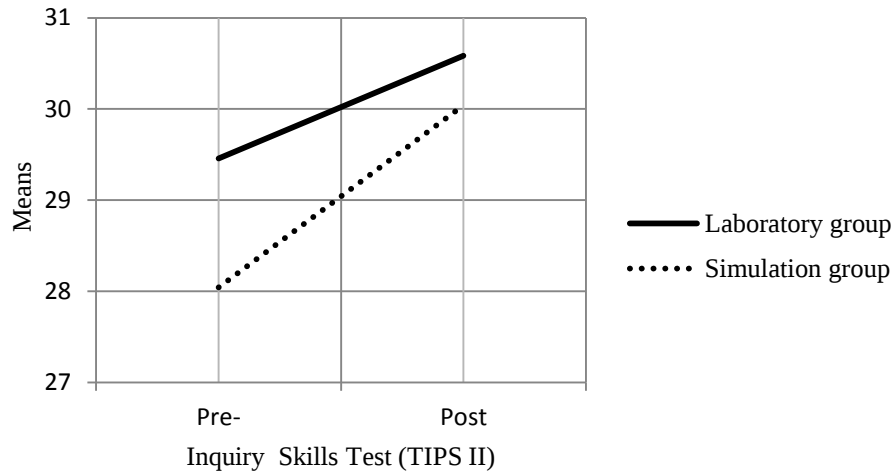
Gain in the post skills scores	Number of students	
	Simulation group	Laboratory group
0	4	4
– 1	0	1
– 2	4	2
– 3	0	2

Until now, neither the examination of the means and standard deviation nor the close observations of the individual skills tests scores revealed obvious differences between the simulation group and the laboratory group. Another form of graphical representation may not show the same trend.

Figure 5.3 describes two plots representing the means of students' scores in the pre- and post-skills test in laboratory group and simulation group. The graph shows an increase in the means in both groups. However, it appears that the line graph of the simulation group is steeper than that of the laboratory group. It seems that students in the simulation group obtained a

slightly higher gain in TIPS scores than students in the laboratory group, despite the fact that the graph of the simulation group was lower than that of the laboratory group.

Figure 5.3 Plots the means of students' scores in the pre- and post-TIPS by group



In conclusion, as a general trend, students from both groups obtained higher scores in the post-TIPS after they had conducted Newton's second law activities. Therefore, inferential statistics was needed to determine whether the gain in TIPS scores was statistically significant.

5.2 Inferential statistics

The data were compiled and analyzed using SPSS for Windows. The alpha value was set at 0.05 level of significance to test the following hypotheses:

Hypothesis 1: students taught via inquiry-based computer simulation will significantly develop their inquiry skills better than students taught via inquiry-based laboratory.

Hypothesis 2: students taught via inquiry-based laboratory will significantly develop their inquiry skills better than students taught via inquiry-based computer simulation.

Hypothesis 3: students taught via inquiry-based laboratory and inquiry-based computer simulation will significantly develop their inquiry skills.

Initially, a one-way analysis of variance (ANOVA) was performed to test the statistical differences between the two conditions on the conceptual understanding in mechanics, as indicated by the MDT scores.

The pre-experimental study results

The screening with the physics teacher indicated no major differences between students' level of conceptual understanding in mechanics. The results of one-way ANOVA supported the initial screening and showed that students across the two groups were not significantly different in their level of conceptual understanding ($F(1, 47) = 0.278$).

Table 5.6 One-way ANOVA test

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.768	1	1.768	0.278*	0.600
Within Groups	298.640	47	6.354		
Total	300.408	48			

*p < .05

Therefore, the students' MDT scores did not threaten the relationship between learning tool (independent factor) and students' scores of TIPS (II) (dependent factor).

The experimental study results

A 2 Learning Tool $\times$ 2 Time split-plot repeated measures ANOVA analysis was conducted (Table 5.7), and showed that the interaction effect was not significant ($F(1,47) = 1.345$). This suggested that the effect of learning activities over time on the development of student inquiry skills did not depend on the type of learning tools used during the activities. Hence, *hypotheses 1* and *2* were rejected.

Table 5.7 Split-plot Learning Tool $\times$ Time Analysis of Variances (ANOVA)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Between subjects					
Intercept	85424.866	1	85424.866	3300.7	0.000
Learning Tool	23.56	1	23.56	0.910*	0.345
Error	1216.399	47	25.881		
Within subjects					
Time (pre- and post)	59.790	1	59.790	17.207**	0.000
Learning Tool $\times$ Time	4.688	1	4.688	1.349***	0.251
Error (time)	163.312	47	3.475		

* $p < .05$, ** $p < .05$, *** $p < .05$

The repeated measures test also showed that there was no significant main effect for the Learning Tool ($F(1,47) = 0.910$). This suggests that the type of learning tool did not significantly influence the development of student's inquiry skills. However, the repeated measures test revealed a significant main effect for the within-subjects factor ($F(1,47) = 17.207$). This suggested that there was statistically significant difference between students' scores in the pre-TIPS (II) and the post TIPS (II), regardless of what type of learning tool they had used in Newton's second law activities. Therefore, *hypothesis 3* was supported.

Chapter 6: Discussion

This chapter discusses the results of the study. The results presented in chapter 5 will be discussed in the following order: the effects of learning tools on the development of student's inquiry skills, the impacts of teaching strategy on guided-inquiry activities, the limits of the study, and opportunities for further investigations.

Section 6.1 compares the impacts of the computer simulation and manipulation of concrete objects on the development of students' inquiry skills, after they have conducted Newton's second law activities. The section also discusses the challenges students have faced during their experiments.

Section 6.2 discusses the impacts of the teaching strategy on the development of students' inquiry skills, and identifies the measures that should be taken to make the values of the teaching strategy most advantageous.

Finally section 6.3 discusses the scopes and limitations of the study, and suggests new areas for future investigations.

The main objective of this study is to compare the effectiveness of the visualization via an interactive computer simulation and the manipulation of concrete objects in a physics lab on the development of students' inquiry skills in mechanics. This comparison focuses on the impact of two specific learning tools on the development of students' inquiry skills, and find out which tool is preferred and in which learning circumstances.

6.1 Effects of learning tools on the development of the inquiry skills

The results of this research showed that in a guided inquiry-based learning environment, visualization via interactive computer simulations **or** manipulation of concrete objects in a physics lab can both be used as a learning tool to develop students' inquiry skills in mechanics.

The positive effects of these intellectual learning tools (mind-tools) in supporting the development of students' inquiry skills are consistent with the cognitive tools that support structures that aim to compensate for students' knowledge or inquiry skills deficiencies (Jonassen, 1996; Linn, 2004; Manlove, 2006).

Comparison between the computer simulation and laboratory groups

The theoretical framework of this study anticipated the possible role of the interactive simulation, and the manipulation of concrete objects in helping students to practice inquiry skills by providing them with opportunities to adjust their performance in each engagement. Students from both groups performed Newton's second law activities and were engaged in different inquiry tasks that involved conducting experiments to relate between force and acceleration, manipulating and controlling variables, plotting graphs, drawing conclusions, and elaborating Newton's laws in new situations.

Despite the fact that the two learning tools did not show a statistically significant difference in enhancing the development of students' inquiry skills, subjective observations of the classroom environment made by the researcher may give some insights on the effectiveness of the computer simulation and the manipulation of concrete objects.

1. Developing inquiry skills via the visualization of interactive computer simulations

In their attempts to establish relationships between net force, mass, and acceleration, the students in computer simulation group not only had the chance to manipulate the values of net force and observe the resulting type of motion several times, but they also visualized the effect of specific components of the net force on the acceleration of an object, which they would not have identified if they were to manipulate concrete objects.

In this effort, on one hand, students in the simulation group gathered a discrete set of data and presented it in perfect graphs and drew acceptable conclusions about the relationships between net force and acceleration as indicated in their booklets. On the other hand, they benefited from the performance with less calculation to free more cognitive time to discuss and clarify their models, and foster their understanding of the influence of different types of forces (friction, normal force, external force, and gravity) on objects' motion.

Consequently, students in the simulation group could use their newly gained abilities and experiences to participate actively in analyzing and interpreting data in terms of their existing cognitive structure, and hence gear up these benefits to resolve any discrepancies between preexisting ideas and the observations in the simulations.

2. Developing inquiry skills via manipulation of concrete objects in a physics laboratory

In comparison, students in the physics laboratory were given opportunities to manipulate concrete objects to establish relationships between net force, mass, and acceleration (Newton's second law experiment). The concrete objects provided real experiences with natural phenomena (motion of a dynamic cart) that allowed students to study what influenced the motion (acceleration) of a dynamic cart. Some of the students were able to distinguish between the mass of the moving system as a control variable, and the mass hung vertically as the source of the external pulling force (Figure 6.1). With appropriate guidance from the teacher, the experimental set up allowed students to observe the influence of the external force on the acceleration of the whole system.

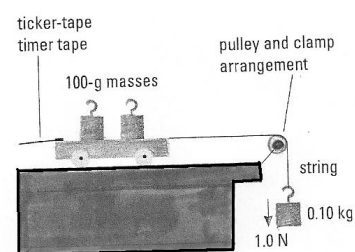


Figure 6.1

In this effort, students were involved in a series of problem solving tasks in order to calculate the resulting acceleration. First, students measured a set of physical quantities using

ticker-tape timer, and then substituted these measurements in the equations of motion to finally calculate the acceleration of the system. Students worked in small collaborative groups to discuss alternative ways to obtain the necessary measurements when other methods failed.

As a result, in a large part of their Newton's second law activities, students were engaged in actions (and skills) that constituted an integral part of the inquiry laboratory activity, such as asking questions, planning a general strategy before starting, suggesting alternative procedures, correcting errors, draw conclusions based on evidences, justifying opinions, and seeking reasons for aspects of current work. Therefore, it is logical to find that students in the laboratory group practiced and developed their inquiry skills during their study.

The comparisons between the interactive computer simulation and the laboratory conditions further support the conclusion that both tools are beneficial to allow the students to practice different components of inquiry skills in mechanics. Overall, these tools supported the development of students' abilities to design and conduct investigation and make scientifically accepted explanations regarding what influences the motion of an object. These findings lead to the same rationale and conclusion obtained by previous research studies (Kipnis, 2007; Windschit, 2000).

However, prior research has shown that the development of inquiry skills is typically difficult to achieve in a short time-effect of inquiry instruction, and it is always challenged by the abilities of students to self-direct (self-regulate) their inquiry investigation (De Jong, 2006). This view was noticed during this study as well. The following challenges have been recorded from the researcher's diary, and students' booklets:

1. Challenges due to limitations of the assisting learning tools:

- Due to instrument errors, some of the data gathered from the ticker-tape timer was not acceptable because it produced undefined graphs.
 - The nature of the experimental setup in the laboratory group (Figure 6.1) could not help part of students to demonstrate a clear understanding of the type of external force exerted on the dynamic cart; they confused it with the total mass of the dynamic system. This confusion has been shown to state unacceptable conclusions to relate net force and acceleration.
 - Although students from both groups performed the learning activities in longer periods than have been expected, students in the laboratory group did spend more time to complete the activities. The slow pace performance in the laboratory group was mainly due to the difficulties experienced while measuring quantities, carrying out mathematical calculations, and plotting graphs. In the simulation group, the computer carried out most of the necessary measurements and calculations.
2. Challenges due to lack of students' abilities:
- Students from both conditions were not able to use their assigned learning tool in designing an investigation and relating between variables. They could not obtain a sequence of procedures; rather they expressed their expectations of what relationships between the variables might be.
3. Other challenges:
- Students from both groups did not use their assigned learning tool appropriately to elaborate the concepts of Newton's second law in new situations. Rather, they relied on their newly acquired understanding of the relationship between net force, mass, and

acceleration; and responded poorly to the questions posed in *the elaborate* phase (see Appendices D and E – *The elaborate* phase).

- In the *elaborate* phase students in the laboratory group were not able to utilize their experimental setup to test how the surface nature of the inclined plane affects an object's motion (Student's Guide – Appendix E). It was not clear, whether this problem was due to the limitations of the experimental setup by itself, or due to the lack of students' abilities to conduct the experiment.

The major part of the above stated challenges, however, was compensated by a successful implementation of other components of the teaching strategy. This implementation was not an isolated experience. It appeared to be of most value to guide students through the 5Es learning cycle.

6.2 The impacts of the teaching strategy on the implementation of the Newton's second law activities

The implementation of the teaching strategy is linked to four components: the learning tools, students' booklets, the physics teacher scaffolding, and students' collaborations. The impacts of the learning tools are discussed in section 6.1.

Students' booklets

Student's Guide (see appendices IV and V) employed various representations in assisting students to progress through the 5Es learning phases. At the beginning of each phase, students were guided by a consistent organizational structure to describe the inquiry tasks, what they needed to do, and what the next inquiry task would be. Then, students were presented with real-life stories or situations. These examples served as artifacts to guide students to recall their preexisting knowledge in order to predict a scenario of the expected type of motion as in Christopher's story and the towed cars (see Appendices D and E); to explain situations in order

to derive a general statement as in the racing car and drag-racing car example (see Appendices D and E); or to elaborate concepts on new situations as in the downhill skiing example. The real-life examples and the associated questions assessed the change of students' understanding and served as metacognitive aids for students to realize how their understanding of force and motion has changed.

Collaboration

Newton's second law activities are designed to foster collaboration. This feature is difficult to separate from the development of inquiry skills, and utilization of learning tools. One primary strategy for fostering collaboration is the extensive use of small and large-group discussions. For example, when introducing Christopher's story, small group discussions are used to answer the posed questions followed by a class discussion to review students' responses, their understanding of nature of force, and its influence on object's motion. Explicit connections were made during these discussions such as the effect of friction force on object's motion. Through many other discussions students identified the factors affecting the motion of objects and determined the relationships between these factors using appropriate terminologies.

Another strategy engaged students in small collaborative groups to conduct Newton's second law experiment, and receive feedback and reflection on their performance. For instance, when examining the relationship between variables, students reached consensus on the variables they were going to investigate, and at the end of the investigation they discussed with the class the rationale of the relationship between these variables.

Physics teacher scaffolding

Students have difficulties with several aspects of inquiry including designing procedures to conduct an investigation, making decisions concerning how best to proceed, and understanding how concepts are related to the investigation (Krajcik, 1998).

The physics teacher, in this study, used the space provided during and between the phases of the 5Es learning cycle to explicitly relate the results of the experiment to discuss the next direction of the inquiry, share and negotiate the meaning of experiments, and provide information relevant to the investigation. He teacher added information continuously during the learning activities. He discussed with the students individually and collectively, ways to pursue the investigations and ways to present data in graphs. All of the questions posed after the completion of a particular segment of the 5Es learning cycle were discussed and put on the board.

The flexibility of the teaching strategy has added more strength in its role to support guided-inquiry activities. On one hand, the collaborative groups performed Newton's second law activities independent from each other. Some groups were progressing through 5Es in a normal pace, and others were lagging behind. The physics teacher scaffolding and the collaborations between groups helped the lagging groups to catch up with the rest of the class. On the other hand, it is possible to implement the whole strategy or part of it to accomplish particular element(s) of a physics lesson plan. Currently physics teachers use a variety of teaching strategies in classroom including direct-instruction, demonstrations, conducting experiments, inquiry activities, and group discussions. This is especially true for engaging students in a variety of short activities in order to reduce the negative effect that might develop during intensive long term tasks of the same kind.

While the implementation of the teaching strategy in this study indicated that guiding students through inquiry tasks and phases is feasible, the researcher's class observations revealed that the teaching strategy can be most advantageous under the following conditions:

- The utilization of learning tools is an essential component of the teaching strategy. Students should not be dictated with a specific learning tool, they should have the opportunity to select the most effective learning tool for the appropriate inquiry task. From this, it follows that visualization of natural phenomena via interactive computer simulation is the best selection for establishing relationships between variables and representing data in graphs; because students can work more independently to conduct an investigation than manipulate concrete objects in a physics laboratory. The extra time can be used to engage students in other tasks that are potentially useful for their learning. On the other hand, from this study, it appears that manipulation of concrete objects would be a better selection when it comes to performing specific types of measurement as required by curriculum objectives, and to practice problem solving tasks.
- It is likely that the scenarios given in Student's Guide might look complicated. Perhaps a careful review of the wording of the examples and the nature of the scenarios presented in the examples will be beneficial to a diverse group of students.

Overall, this study indicates positive effects for interactive computer simulation and manipulation of concrete objects in developing of students' inquiry skills in guided inquiry-based activities. But as with most research, more questions have been raised than answered. Recommendations are needed to determine directions for further investigations that would be particularly interesting to follow.

6.3 Future research

The teaching strategy was not inclusive for students' diversity in terms of gender, physical abilities, and cultural background. This limitation narrows the study's scope to investigate the effect of the teaching strategy on the skills development of a diverse group of

students. Further research with a larger sample size could investigate how gender, physical abilities, and cultural background have an impact on students' abilities to use cognitive tools to develop their inquiry skills. One suggestion would be to examine whether real-life examples used in the learning activities promote diversity and multiculturalism during inquiry tasks. These real-life examples may come in the form of contexts that interest a diverse body of students.

Another research direction would be particularly interesting to follow. It is important to find out how a particular component of inquiry skills may be developed. This emphasis will certainly focus on the efforts to design specific teaching strategy and its associated assessment tools to address the deficiency of a specific skill.

In this study, the teaching strategy embedded computer simulation and manipulation of concrete objects to tackle a variety of inquiry skills (graphing, designing procedures, testing hypothesis, and identifying variables) that has been developed with no distinctions. Neither the results of the study nor the TIPS skills test were conclusive to determine which component of the inquiry skills was particularly dominating the skills development.

In addition, students from laboratory practiced other categories of skills (such as problem solving skills) that were not targeted in the study, and obviously the inquiry skills test (TIPS) could not evaluate those skills properly. Consequently, further research is needed to determine which learning tool or tools that can be utilized to assist students develop a particular skill, and how skills assessment instruments can be designed and validated to distinctively detect the development of a number of these skills.

Furthermore, this research was done with grade 11 students in the university preparation section, in which they were doing 75 minutes of a physics lesson every day. The intensive experience in physics classes has been reflected in the high scores of the pre- skills test (see

section 5.1), which may have caused a ceiling effect and limited any remarkable development of students' inquiry skills. Further research with less-skilled students could be undertaken to investigate the potentials to make drastic improvement in students' inquiry skills.

One recommendation would be to utilize a comprehensive learning tool such as Micro-computer Based Laboratory (MBL). The MBL can be seen as a middle ground in which concrete objects can be manipulated around a natural phenomenon and then interfaced with computer simulation to conduct further analysis. These kinds of features are potentially useful for learning to compensate students' deficiencies in measurement and graphing interpretation skills (Thornton & Sokoloff, 1990).

Finally, beside the needs to address the use of a variety of learning tools in physics classes to raise students' awareness of their inquiry skills deficiencies and how to correct them, further research is necessary to determine how these skills might support students' efforts to understand physics concepts and theories. This would provide a clear definition to the required level of students' inquiry skills and prior knowledge before they begin to learn new physics concepts or theories.

Chapter 7: Conclusions

This chapter presents a summary of the results and the discussions, as well as the educational implications of this study. It also highlights the recommendations based on the findings, the limitations of the study, and areas for further research.

The main objective of this study was to compare the effectiveness of visualization via interactive computer simulation and the manipulation of concrete objects in a physics laboratory on the development of students' inquiry skills in mechanics.

In order to achieve the above stated aim, a teaching strategy was designed to guide students through 5Es learning cycle. The Mechanics Diagnostic Test (MDT) with 20 multiple-choice items (Appendix B) was used as a pre-experimental measure to detect any differences in students' conceptual understanding in mechanics. Students from one group performed Newton's second law activities using computer simulation, and the other group performed the same activities using concrete objects. The Integrated Process Skills Test (Appendix C) was used as a pre- and post-inquiry skills test to measure any development of students' inquiry skills during Newton's second law activities.

7.1 Summary of the results and discussions

The results of the study showed that there were no significant interaction effects between the types of learning tool used during the activities and the development of the students' inquiry skills measured by the pre-TIPS (II) and the post TIPS (II). Students from both conditions significantly developed their inquiry skills over the time provided for the learning activities. From this, the students' level of conceptual understanding in mechanics did not influence their efforts to develop their inquiry skills.

The answer to the first research question, which sought to discuss the possible impacts of the interactive computer simulation on the development of students' inquiry skills, concluded that computer simulations hold promises to assist students in identifying and establishing relationships between variables. Working with computer simulations allows students to work independently and save valuable class time for other learning activities. It should be noted, however, that the current simulations may not promote real experiences with natural phenomena.

The second research question discussed the possible impacts of the manipulation of concrete objects on the development of students' inquiry skills. This discussion concluded that, with careful guidance students can benefit from manipulation of concrete objects in a science laboratory. Students can challenge their ideas against natural phenomena and observe how it actually works, practice different components of inquiry skills, and realize how scientists work in real life. A successful laboratory experiment however, requires good preparation and longer time to perform, which may not be possible at all times.

In conclusion, if technology is used in balance with real experiences and is placed in its proper context, it can enrich the classroom by providing new and contrasting contexts in which to understand experiences (Feldman, 2000).

7.2 Educational implications of results and recommendations

Based on the results of this study and the discussions, the educational implications of the research may be summarized as follows:

- This study contributes to education under the categories of research and development:
 - In terms of research it aims to compare the effectiveness of the two learning tools on the development of students' inquiry skills in mechanics.

- The teaching strategy that can be developed from this study may be used to guide high school students through Newton's second law activities, and thus contribute to the enhancement of inquiry-based learning.
- The results confirm that conclusions drawn by previous research studies regarding the potential benefits of computer technologies and science laboratory in science education.
- Based on the findings, high school physics teachers will be able to decide which of the compared learning tools might be appropriate to utilize in inquiry-based activities in physics.

7.3 Limitations of the study

The study has certain limitations that should be taken into consideration when interpreting the results. The limitations pertain to the following:

- The study did not take students' diversity into account, which made the results less conclusive from the point of view of gender, physical abilities, and cultural background.
- The small sample size limits the study's generalizability therefore, the results are subjected to the conditions and learning circumstances that occurred during this study.
- The teaching strategy embedded two learning tools to tackle the five inquiry skills. The results were not specific enough to identify any particular inquiry skill that lead to their overall improvement.

7.4 Areas for future research

The results from this study present further research opportunities:

- Investigate how a diverse body of students can change the effect of learning tools on the development of their inquiry skills

- Test the effectiveness of Micro-computer Based Laboratory on the development of students' inquiry skills and knowledge construction especially with less skilled students
- Determine how the development of inquiry skills might support students' efforts to understand physics concepts and theories
- Design strategies and assessment tools to target the development of a specific skill
- Determine the effectiveness of new strategies in imparting learning science as inquiry.

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Appendix A: Action Plan

First event: Pre-skills Test (35 min.)

One day before the event	During the event	After the event	Remarks
<i>The physics teacher is expected to:</i> • deliver a short orientation to the students regarding the upcoming physics project (Letter of Information will be provided); • hand out the Assent Forms; and • ask students to hand in the Consent Forms to their parents/guardians. <i>The researcher will prepare students' coded tags.</i>	<i>The physics teacher is expected to:</i> • state the purpose of the skills test as a tool to assess student's inquiry skills; • state: the test is in MCQ format; • assure to students that their scores in the skills test will not be used in the ongoing school assessment. <i>The physics teacher will administer the skills test.</i> <i>The researcher will hand out the coded tags.</i> <i>The researcher will be available as an invigilator.</i>	<i>The researcher will:</i> • mark the pre-skills test; • keep students' answer sheets and the test materials in a safe locker in the supervisor's office at the University of Ottawa; • record students' scores in a passworded excel book.	For ethical reasons, every student will have his/her coded tag and will be asked to stick it on during the whole project. For example, A-13 is the 13 th student in the alphabetically ordered list of group A.

Second event: Questionnaire and training session

Before the event	During the event	After the event	Remarks
<i>The physics teacher will choose the relevant questions from MDT.</i> <i>The researcher will visit the classroom to make sure everything is working properly and in place.</i>	<i>The physics teacher will:</i> • administer MDT questionnaire of conceptual understanding in mechanics; • distribute the Student's Guides and begin the training session; <i>The researcher will be available to provide any possible assistance.</i>	<i>The researcher will mark the questionnaire responses and accordingly distribute (with the teacher) the students in small homogenous groups.</i>	The results of MDT will be used to distribute students in small. Every two students with similar levels of conceptual understanding will be grouped together.

Third event: Newton's second law activities

Before the event	During the event	After the event	Remarks
<i>The researcher will visit the classroom to make sure everything is working properly and in place.</i>	<i>The physics teacher will facilitate Newton's second law activities as described in the Teacher's Guide and Student's Guide.</i> <i>The researcher will be available to provide any possible assistance.</i>	<i>The researcher will collect students' guides for further analysis.</i>	The researcher will provide assistance or troubleshooting to any possible failure in the simulation software.

Forth event: Post skills Test (25-30 min.)

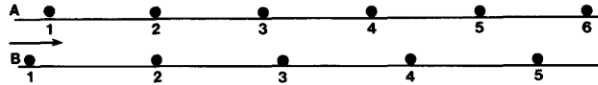
Before the event	During the event	After the event	Remarks
	<i>The physics teacher will administer the post skills test.</i> <i>The researcher will be available as an invigilator.</i>	<i>The researcher will:</i> • receive the Consent Forms and Assent Forms; • mark the post skills test; • keep students' answer sheets and the test materials in a safe locker in the supervisor's office at the University of Ottawa; • record students' scores in a passworded excel book.	Students' guides will be returned to students to keep.

Appendix B: Mechanics Diagnostic Test (MDT)

Questions relevant to grade 11 physics course were the only questions administered to the students, which were: 1, 2, 4, 6, 7, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 26, 30, 31, and 32.

MECHANICS DIAGNOSTIC TEST

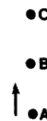
(I) Two balls A and B move at *constant* speeds on separate tracks. Positions occupied by the two balls at the *same time* are indicated in the figure below by *identical numbers*. The arrow indicates the direction of motion. Starting points are not shown.



(1) Do the two balls ever have the *same speed*?

- (a) Yes, at instant "2."
- (b) Yes, at instant "5."
- (c) Yes, at instant "6."
- (d) Yes, at instants "2" and "6."
- (e) No.

(II) The accompanying figure shows a ball thrown vertically *upwards* from point A. The ball reaches a point *higher* than C. B is a point halfway between A and C (i.e., $AB = BC$). *Ignoring air resistance*,



(2) What is the *speed* of the ball as it passes point C compared to its speed as it passes point B?

- (a) Half its speed at point B.
- (b) Smaller than that speed, but not necessarily half of it.
- (c) Equal its speed at point B.
- (d) Twice its speed at point B.
- (e) Greater than that speed, but not twice as great.

(3) On its way *up*, what *force(s)* act on the ball?

- (a) Its weight, vertically downward.
- (b) A force that maintains the motion, vertically upward.
- (c) The downward weight and a constant upward force.
- (d) The downward weight and a decreasing upward force.
- (e) An upward force, first acting alone on the ball from point A to a certain higher point, beyond which the downward weight starts acting on the ball.

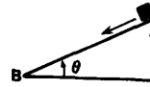
(4) After the ball reaches its highest point above C, it reverses direction to fall straight down. On its way *down*, how does the *speed* of the ball as it passes *point B* compare to its speed as it passed the *same point* on its way up?

- (a) Smaller than the speed it had on the way up.
- (b) Equal to the speed it had on the way up.
- (c) Double the speed it had on the way up.
- (d) Greater than that speed, but not twice as great.
- (e) Cannot be determined from the provided information.

(5) If point A is high enough, and still ignoring air resistance, does the ball ever reach a *speed limit* that it maintains afterwards without going faster or slower?

- (a) Yes, on the way up.
- (b) Yes, on the way down.
- (c) No.
- (d) Cannot be determined from the provided information.

(III) The accompanying figure shows a block that is released from the top A of an incline of given length AB and slope (angle) θ .



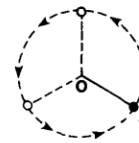
(6) What variable(s) affect the *speed* that the block reaches at the bottom B of the incline?

- (a) Shape of the block.
- (b) Surface of the incline.
- (c) Air density.
- (d) Shape of the block and air density.
- (e) Shape of the block, surface of the incline, and air density.

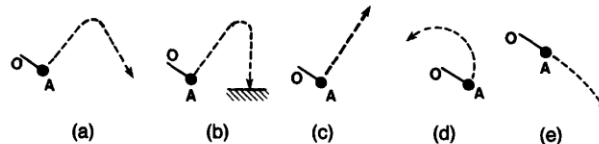
(7) Suppose we *ignore air resistance*, and the incline is *frictionless*. What variable(s) affect the *speed* that the block reaches at the bottom B of the incline?

- (a) Shape of the block.
- (b) Mass of the block.
- (c) Shape and mass of the block.
- (d) Density of the block.
- (e) None of the above.

(IV) The accompanying figure shows a ball attached to a string that you hold in your hand at point O, and rotate at high speed in a *vertical plane* in front of you. The circle shows the path of the ball, and the straight lines from the center O represent different directions of the string as you rotate it in the direction of the arrows. When the string reaches the *direction OA*, you *let the ball go*. Ignoring air resistance and any effect the string might have,



(8) Which of the paths below will the ball follow *after* you let it go at A?



(9) If you have chosen path (a), (b), or (d) from question (8), the *speed* of the ball along the path is:

- (a) Constant.
- (b) Decreasing from A to the top of the path, increasing thereafter, on the way down.
- (c) Decreasing from A to the top of the path where that speed becomes zero, increasing thereafter, on the way down.
- (d) Increasing for a while, and constant thereafter.
- (e) Increasing for a while, then decreasing until the ball reaches the top of the path. That speed increases thereafter.

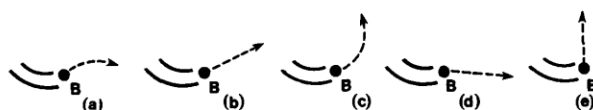
If you have chosen path (c) or (e) from question (8), the *speed* of the ball along the path is:

- (a) Constant.
- (b) Continuously increasing.
- (c) Continuously decreasing.
- (d) Increasing for a while, and constant thereafter.
- (e) Decreasing for a while, and constant thereafter.

(V) The accompanying figure shows a hollow, circular tube laid on a *frictionless, horizontal* table. You are looking down at the table. A ball is shot into the end A of the tube to leave the other end B at high speed.



(10) Which of the paths below will the ball follow on the table, *after* it leaves the tube?



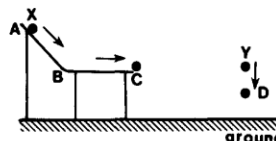
(11) The *speed* of the ball along the path you have chosen is:

- (a) Constant.
- (b) Continuously increasing.
- (c) Continuously decreasing.
- (d) Constant for a while, and continuously increasing thereafter.
- (e) Constant for a while, and continuously decreasing thereafter.

(12) On the table, and along the path you have chosen, what *force(s)* act on the ball?

- (a) The weight of the ball, vertically downward.
- (b) A force from the table, vertically upward.
- (c) A horizontal force, in the direction of motion.
- (d) The first two forces above.
- (e) All three forces above.

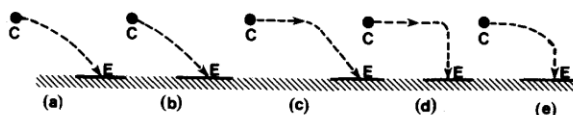
(VI) The left side of the accompanying figure shows a ball X in motion. The ball slides down an incline AB, then on a *frictionless, horizontal* track BC. At C, the ball leaves the track. Ignoring air resistance:



(13) The speed of the ball on the horizontal track BC is:

- (a) Constant.
- (b) Continuously increasing.
- (c) Continuously decreasing.
- (d) Increasing for a while, and constant thereafter.
- (e) Constant for a while, and decreasing thereafter.

(14) Which of the paths below will the ball follow *after* it leaves the track at C?



(15) The *speed* of the ball along the path you have chosen is:

- (a) Constant.
- (b) Continuously increasing.
- (c) Continuously decreasing.
- (d) Constant for a while, and increasing thereafter.
- (e) None of the above.

(16) Beyond C, and *along the path* you have chosen in question (14), what *force(s)* act on the ball?

- (a) The weight of the ball, vertically downward.
- (b) A horizontal force that maintains the motion.
- (c) A force whose direction changes in the direction of motion.
- (d) The weight of the ball and a horizontal force.
- (e) The weight of the ball and a force in the direction of motion.

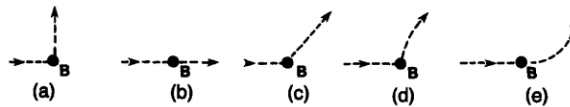
At the *same time* that ball X in the original figure of part VI above leaves the track at C, and from the *same height* as C, a ball Y identical to ball X is released from rest to fall vertically downward.

- (17) When ball Y reaches *point D*, where would ball X be?
- At the same height as D.
 - Above D.
 - Below D.
 - The position of X would depend on how high D is.
 - None of the above.
- (18) Which ball reaches the ground first?
- Ball X.
 - Ball Y.
 - The two balls reach ground at the same time.
 - It depends on how high C is.
 - None of the above.
- (19) Which ball reaches the ground with the *greatest speed*?
- Ball X.
 - Ball Y.
 - The two balls reach ground at the same speed.
 - It depends on how high C is.
 - None of the above.
- (20) If track *BC* was extended beyond C so that ball X would never leave that track, where would that ball be at the *same time* ball Y hits the ground?
- Vertically above E, where ball X hit the ground in question (14).
 - To the right of E.
 - To the left of E.
 - It depends on how high C is.
 - None of the above.

(VII) In the accompanying figure, you are looking *down* at a hockey puck sliding at *constant speed* on a frictionless, horizontal surface, from point A to point B. When the puck reaches *point B*, it receives a *horizontal kick* in the direction of the heavy-print arrow.



- (21) Which of the paths below will the ball follow on the horizontal surface after it receives the kick at B?



- (22) What is the *speed* of the puck *just after* it receives the kick at B?
- Equal to the speed u it had before it receives the kick.
 - Equal to the speed v it acquires from the kick, and independent of the speed u it had before.
 - Smaller than any of the two speeds u and v .
 - Equal to the arithmetic sum of speeds u and v .
 - Greater than any of speeds u or v , but smaller than the arithmetic sum of the speeds.

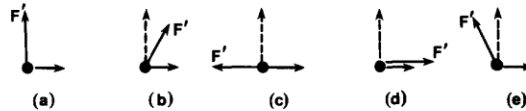
(23) *Along the path* you have chosen, how is the puck's speed *after* it receives the kick at B?

- (a) Constant.
- (b) Continuously increasing.
- (c) Continuously decreasing.
- (d) Increasing for a while, and constant thereafter.
- (e) Constant for a while, and decreasing thereafter.

(VIII) In the accompanying figure, you are looking down at a puck sliding on a horizontal surface. A constant force F acts on the puck as indicated by the solid arrow.



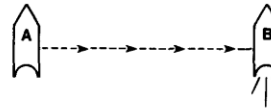
(24) If the puck is to be driven in the direction of the dotted line, a *second* force F' must act on the puck in addition to F , as described by:



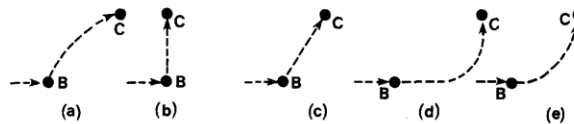
(25) When the two forces act simultaneously on the puck, the *speed* of that puck along the dotted line is:

- (a) Constant.
- (b) Continuously increasing.
- (c) Continuously decreasing.
- (d) Increasing for a while, and constant thereafter.
- (e) Constant for a while, and decreasing thereafter.

(IX) The accompanying figure shows a rocket coasting in space in the direction of the dotted line. Between A and B, *no outside forces* act on the rocket. When it reaches point B, the rocket fires its engines as shown, and at a constant rate until it reaches a point C in space.



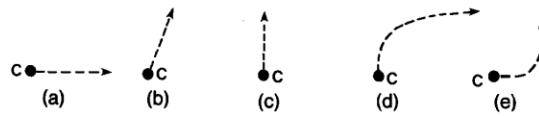
(26) Which of the paths below will the rocket follow from B to C?



(27) As the rocket moves from B to C, its *speed* is:

- (a) Constant.
- (b) Continuously increasing.
- (c) Continuously decreasing.
- (d) Increasing for a while, and constant thereafter.
- (e) Constant for a while, and decreasing thereafter.

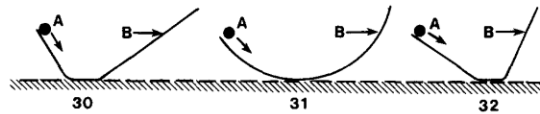
(28) At C, the rocket's engines are turned *off*. Which of the paths below will the rocket follow beyond C?



(29) *Beyond C*, the *speed* of the rocket is:

- (a) Constant.
- (b) Continuously increasing.
- (c) Continuously decreasing.
- (d) Increasing for a while, and constant thereafter.
- (e) Constant for a while, and decreasing thereafter.

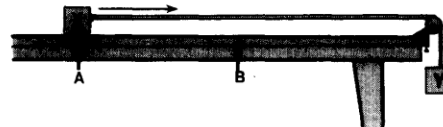
(X) The three figures below show *frictionless* tracks, set in a vertical plane. A ball is released from rest from the top A at the left side of each of the tracks.



Questions (30), (31), and (32): Where is the *highest point* the ball can reach on the right side of each of the tracks?

- (a) Point B which is at the same height as point A.
- (b) Lower than B.
- (c) Higher than B.
- (d) It depends on how high point A is.
- (e) It depends on how big the ball is.

(XI) The figure below shows two blocks X and Y connected by means of a massless string that goes over a frictionless pulley. When released, block Y pulls block X in the direction of the arrow on a *frictionless, horizontal* table. Ignoring air resistance:



(33) The *speed* of block X is:

- (a) Constant.
- (b) Continuously increasing.
- (c) Continuously decreasing.
- (d) Increasing for a while, and constant thereafter.
- (e) Constant for a while, and decreasing thereafter.

(34) When block X reaches point B, the string breaks. Block X then:

- (a) Stops at B.
- (b) Keeps moving at constant speed.
- (c) Speeds up.
- (d) Slows down.
- (e) Speeds up for a while, then slows down.

Block Y is now replaced by another block Z that exerts on block X *twice the pull* previously exerted by block Y. Block X is reset at point A, and released. Again, when block X reaches point B, the string breaks.

(35) What is the *speed of block X* at point B now compared to the speed it reached at the *same point* when block Y was pulling it?

- (a) Half the speed it reached before.
- (b) Smaller than that speed, but not half of it.
- (c) Equal to that speed.
- (d) Double that speed.
- (e) Greater than that speed, but not twice as great.

(36) *How long* does block X take to reach point B when block Z is pulling it, compared to the duration it took to reach that same point when block Y was pulling it?

- (a) Half the duration it took under the pull of block Y.
- (b) Smaller than that duration, but not half of it.
- (c) Equal to that duration.
- (d) Double that duration.
- (e) Greater than that duration, but not twice as great.

Appendix C: Integrated Process Skills Test II

INTEGRATED PROCESS SKILLS TEST II

INTEGRATED PROCESS SKILLS TEST II

Instructions:

Please use a #2 pencil to complete this test. On your **answer sheet** mark the box below the letter of the best answer. Be careful that the answer number is the same as the question number you are answering. Darken each box completely, being careful not to color in any other boxes. Be sure to completely erase any stray marks.

1. A football coach thinks his team loses because his players lack strength. He decides to study factors that influence strength. Which of the following variables might the coach study to see if it affects the strength of the players?
 - A) Amount of vitamins taken each day.
 - B) Amount of lifting exercises done each day.
 - C) Amount of time spent doing exercises.
 - D) All of the above.
2. A study of auto efficiency is done. The hypothesis tested is that a gasoline additive will increase auto efficiency. Five identical cars each receive the same amount of gasoline but different amounts of Additive A. They travel the same track until they run out of gasoline. The research team records the number of miles each car travels. How is auto efficiency measured in this study?
 - A) The time each car runs out of gasoline.
 - B) The distance each car travels.
 - C) The amount of gasoline used.
 - D) The amount of Additive A used.
3. An auto manufacturer wants to make cars cheaper to operate. They are studying variables that may affect the number of miles per gallon that autos get. Which variable is likely to affect the number of miles per gallon?
 - A) Weight of the car.
 - B) Size of the motor.
 - C) Color of the car.
 - D) Both A and B.
4. A class is studying the speed of objects as they fall to the earth. They design an investigation where bags of gravel weighing different amounts will be dropped from the same height. In their investigation which of the following is the hypothesis they would test about the speed of objects falling to earth?
 - A) An object will fall faster when it is dropped further.
 - B) The higher an object is in the air the faster it will fall.
 - C) The larger the pieces of gravel in a bag the faster it will fall.
 - D) The heavier an object the faster it will fall to the ground.

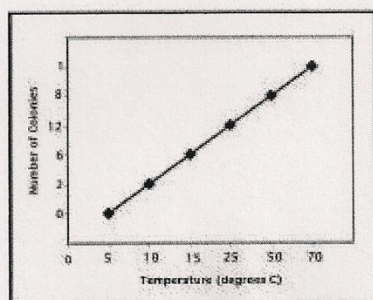
INTEGRATED PROCESS SKILLS TEST II

5. A student in a science class studied the effect of temperature on the growth of bacteria. The student obtained the following data:

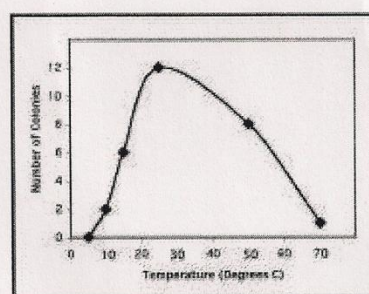
Temperature of the growth chamber (°C)	Number of bacterial colonies
5	0
10	2
15	6
25	12
50	8
70	1

Which graph correctly represents the data from the experiment?

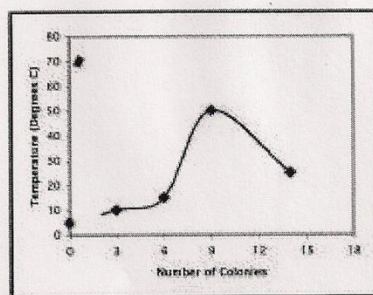
A)



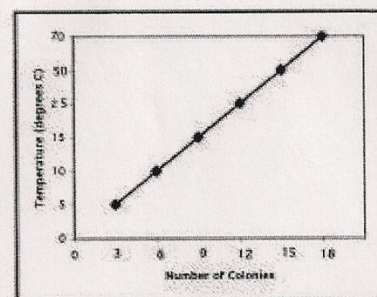
B)



C)



D)



6. A police chief is concerned about reducing the speed of autos. He thinks several factors may affect the automobile speed. Which of the following is a hypothesis he could test about how fast people drive?

- A) The younger the drivers, the faster they are likely to drive.
- B) The larger the autos involved in an accident, the less likely people are to get hurt.
- C) The more policemen on patrol, the fewer the number of auto accidents.
- D) The older the autos the more accidents they are likely to be in.

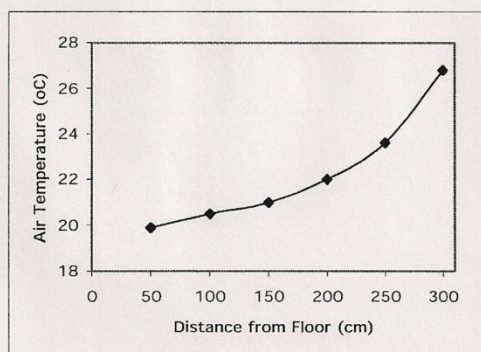
INTEGRATED PROCESS SKILLS TEST II

7. A science class is studying the effect of wheel width on ease of rolling. The class puts wide wheels onto a small cart and lets it roll down an inclined ramp and then across the floor. The investigation is repeated using the same cart but this time fitted with narrow wheels.

How could the class measure ease of rolling?

- A) Measure the total distance the cart travels.
 - B) Measure the angle of the inclined ramp.
 - C) Measure the width of each of the two sets of wheels.
 - D) Measure the weight of each of the carts.
8. A farmer wonders how he can increase the amount of corn he grows. He plans to study factors that affect the amount of corn produced. Which of these hypotheses could he test?
- A) The greater the amount of fertilizer the larger the amount of corn produced.
 - B) The greater the amount of corn, the larger the profits for the year.
 - C) As the amount of rainfall increases, the more effective the fertilizer.
 - D) As the amount of corn produced increases, the cost of production increases.
9. A study is done of the temperature in a room at different distances from the floor. The graph of the data is shown below.

How are the variables related?



- A) As distance from the floor increases, air temperature decreases.
- B) As distance from the floor increases, air temperature increases.
- C) An increase in air temperature means a decrease in distance from the floor.
- D) The distance from the floor is not related to air temperature increases.

INTEGRATED PROCESS SKILLS TEST II

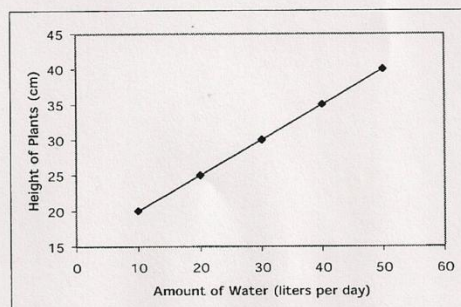
10. Jim thinks that the more air pressure in a basketball, the higher it will bounce. To investigate this hypothesis he collects several basketballs and an air pump with a pressure gauge.

How should Jim test his hypothesis?

- A) Bounce basketballs with different amounts of force from the same height.
- B) Bounce basketballs having different air pressures from the same height.
- C) Bounce basketballs having the same air pressure at different angles from the floor.
- D) Bounce basketballs having the same amount of air pressure from different heights.

11. A study is being done on the amount of water needed to grow plants. Five small garden plots are given different amounts of water. After two months the height of the plants is measured. The data are shown on the graph.

What is the relationship between the variables?



- A) Increasing the amount of water increases the height of the plants.
- B) Increasing the height of the plants increases the amount of water.
- C) Decreasing the amount of water increases the height of the plants.
- D) Decreasing the height of the plants decreases the amount of water.

INTEGRATED PROCESS SKILLS TEST II

Marie wondered if the earth and oceans are heated equally by sunlight. She decided to conduct an investigation. She filled a bucket with dirt and another bucket of the same size with water. She placed them so each bucket received the same amount of sunlight. The temperature in each was measured every hour from 8:00 a.m. to 6:00 p.m.

12. Which hypothesis was being tested?

- A) The greater the amount of sunlight, the warmer the soil and water become.
- B) The longer the soil and water are in the sun, the warmer they become.
- C) Different types of materials are warmed differently by the sun.
- D) Different amounts of sunlight are received at different times of the day.

13. Which of these variables is controlled in Marie's study?

- A) Kind of water placed in the bucket.
- B) Temperature of the water and soil.
- C) Type of material placed in the buckets.
- D) Amount of time each bucket is in the sun.

14. What was the dependent or responding variable in Marie's study?

- A) Kind of water placed in the bucket.
- B) Temperature of the water and soil.
- C) Type of material placed in the buckets.
- D) Amount of time each bucket is in the sun.

15. What was the independent or manipulated variable in Marie's study?

- A) Kind of water placed in the bucket.
- B) Temperature of the water and soil.
- C) Type of material placed in the buckets.
- D) Amount of time each bucket is in the sun.

16. Susan is studying food production in bean plants. She measures food production by the amount of starch produced. She notes that she can change the amount of light, the amount of carbon dioxide, and the amount of water that plants receive. What is a testable hypothesis that Susan could study in this investigation?

- A) The more carbon dioxide a bean plant gets the more starch it produces.
- B) The more starch a bean plant produces the more light it needs.
- C) The more water a bean plant gets the more carbon dioxide it needs.
- D) The more light a bean plant receives the more carbon dioxide it will produce.

INTEGRATED PROCESS SKILLS TEST II

Joe wanted to find out if the temperature of water affected the amount of sugar that would dissolve in it. He put 50 mL of water into each of four identical jars. He changed the temperatures of the jars of water until he had one at 0°C, one at 50°C, one at 75°C, and one at 95°C. He then dissolved as much sugar as he could in each jar by stirring.

17. What is the hypothesis being tested?
 - A) The greater the amount of stirring, the greater the amount of sugar dissolved.
 - B) The greater the amount of sugar dissolved, the sweeter the liquid.
 - C) The higher the temperature, the greater the amount of sugar dissolved.
 - D) The greater the amount of water used, the higher the temperature.
18. What is a controlled variable in Joe's study?
 - A) Amount of sugar dissolved in each jar.
 - B) Amount of water placed in each jar.
 - C) Number of jars used to hold water.
 - D) The temperature of the water.
19. What is the dependent or responding variable in Joe's study?
 - A) Amount of sugar dissolved in each jar.
 - B) Amount of water placed in each jar.
 - C) Number of jars used to hold water.
 - D) The temperature of the water.
20. What is the independent or manipulated variable in Joe's study?
 - A) Amount of sugar dissolved in each jar.
 - B) Amount of water placed in each jar.
 - C) Number of jars used to hold water.
 - D) The temperature of the water.
21. A greenhouse manager wants to speed up the production of tomato plants to meet the demands of anxious gardeners. She plants tomato seeds in several trays. Her hypothesis is that the more moisture seeds receive the faster they sprout. How can she test her hypothesis?
 - A) Count the number of days it takes seeds receiving different amounts of water to sprout.
 - B) Measure the height of the tomato plants a day after each watering.
 - C) Measure the amount of water used by plants in different trays.
 - D) Count the number of tomato seeds placed in each of the trays.

INTEGRATED PROCESS SKILLS TEST II

22. A gardener notices that his squash plants are being attacked by aphids. He needs to get rid of the aphids. His brother tells him that "Aphid-Away" powder is the best insecticide to use. The county agent says "Squash-Saver" spray works the best. The gardener selects six squash plants and applies the powder to three and the spray to three. A week later he counts the number of live aphids on each of the plants.

How is the effectiveness of the insecticides measured in this study?

- A) Measuring the amount of spray or powder used.
- B) Determining the condition of the plants after spraying or dusting.
- C) Weighing the squash each plant produces.
- D) Counting the number of aphids remaining on the plants.

23. Lisa wants to measure the amount of heat energy a flame will produce in a certain amount of time. A burner will be used to heat a beaker containing a liter of cold water for ten minutes.

How will Lisa measure the amount of heat energy produced by the flame?

- A) Note the change in water temperature after ten minutes.
- B) Measure the volume of water after ten minutes.
- C) Measure the temperature of the flame after ten minutes.
- D) Calculate the time it takes for the liter of water to boil.

24. Mark is studying the effect of temperature on the rate that oil flows. His hypothesis is that as the temperature of the oil increases it flows faster.

How could he test this hypothesis?

- A) Heat oil to different temperatures and weigh it after it flows out of the can.
- B) Observe the speed at which oil at different temperatures flows down a smooth surface.
- C) Let oil flow down smooth surfaces at different angles and observe its speed.
- D) Measure the time it takes for oil at different thicknesses to pour out of the can.

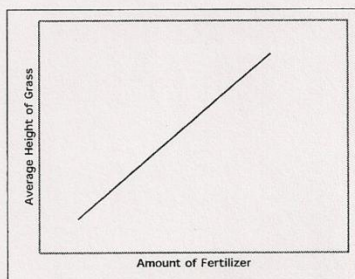
INTEGRATED PROCESS SKILLS TEST II

25. A researcher is testing a new fertilizer. Five small fields of the same size are used. Each field receives a different amount of fertilizer. One month later the average height of the grass in each plot is measured. The measurements are shown in the table below.

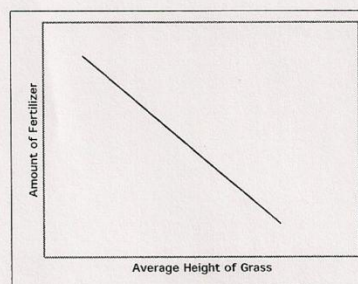
Amount of Fertilizer (kg)	Average Height of Grass (cm)
10	7
30	10
50	12
80	14
100	12

Which graph represents the data in the table?

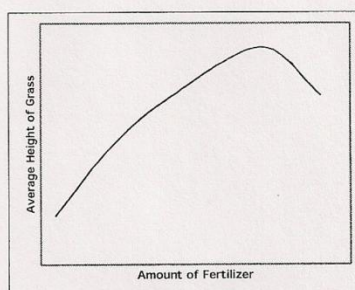
A)



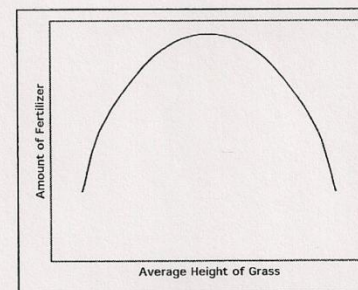
B)



C)



D)



- Make sure that you have not skipped any questions so far.
- You should have filled in answers all the way to the bottom of your answer scan sheet (#1 to #25).
- Your next answer (#26) belongs at the top of the next column.
- Question #26 is on the next page.

INTEGRATED PROCESS SKILLS TEST II

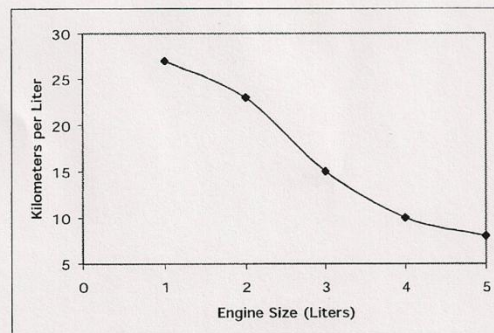
26. A biologist tests this hypothesis: the greater the amount of vitamins given to rats the faster they will grow. How can the biologist measure how fast rats will grow?

- A) Measure the speed of the rats.
- B) Measure the amount of exercise the rats receive.
- C) Weigh the rats every day.
- D) Weigh the amount of vitamins the rats will eat.

27. Some students are considering variables that might affect the time it takes sugar to dissolve in water. They identify the temperature of the water, the amount of sugar and the amount of water as variables to consider. What is a hypothesis the students could test about the time it takes for sugar to dissolve in water?

- A) The larger the amount of sugar the more water required to dissolve it.
- B) The colder the water the faster it has to be stirred to dissolve.
- C) The warmer the water the more sugar that will dissolve.
- D) The warmer the water the more time it takes the sugar to dissolve.

28. A consumer group measures the miles per gallon cars get with different size engines. The results are as follows:



Which of the following describes the relationship between the variables?

- A) The larger the engine the more miles per gallon the car gets.
- B) The fewer miles per gallon the car gets the smaller the engine.
- C) The smaller the engine the more miles per gallon a car gets.
- D) The more miles per gallon for a car the larger the engine.

INTEGRATED PROCESS SKILLS TEST II

A study was done to see if leaves added to soil has an effect on tomato production. Tomato plants were grown in four large tubs. Each tub had the same kind and amount of soil. One tub had 15 kg of rotted leaves mixed in the soil and a second had 10 kg. A third tub had 5 kg and the fourth had no leaves added. Each tub was kept in sun and watered the same amount. The number of kilograms of tomatoes produced in each tub was recorded.

29. What is the hypothesis being tested?

- A) The greater the amount of sunshine the greater the amount of tomatoes produced.
- B) The larger the tub, the greater the amount of leaves added.
- C) The greater the amount of water added, the faster the leaves rotted in the tubs.
- D) The greater the amount of leaves added, the greater the amount of tomatoes produced.

30. What is a controlled variable in this study?

- A) Amount of tomatoes produced in each tub.
- B) Amount of leaves added to the tubs.
- C) Amount of soil in each tub.
- D) Number of tubs receiving rotted leaves.

31. What is the dependent or responding variable?

- A) Amount of tomatoes produced in each tub.
- B) Amount of leaves added to the tubs.
- C) Amount of soil in each tub.
- D) Number of tubs receiving rotted leaves.

32. What is the independent or manipulated variable?

- A) Amount of tomatoes produced in each tub.
- B) Amount of leaves added to the tubs.
- C) Amount of soil in each tub.
- D) Number of tubs receiving rotted leaves.

33. A student is investigating the lifting ability of magnets. He has several magnets of different sizes and shapes. For each magnet, the student weighs the amount of iron filings it picks up. How is the lifting ability of magnet defined in the experiment?

- A) The size of the magnet in use.
- B) The weight of the magnet picking up things.
- C) The shape of the magnet in use.
- D) The weight of the iron filings picked up.

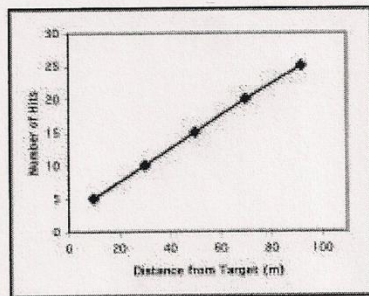
INTEGRATED PROCESS SKILLS TEST II

34. Twenty-five shots are fired at a target from several distances. The table below shows the number of "hits" in 25 shots at each distance.

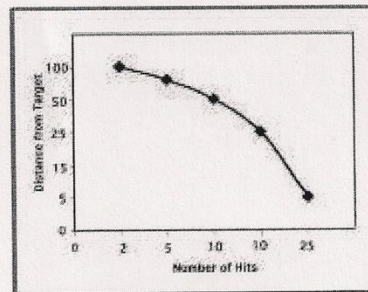
Distance from Target (m)	Number of Hits
5	25
15	10
25	10
50	5
100	2

Which graph represents the data?

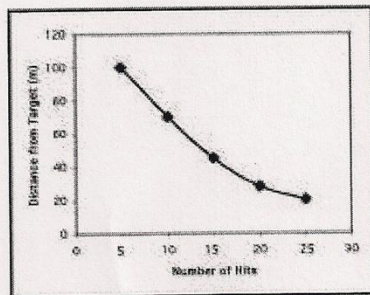
A)



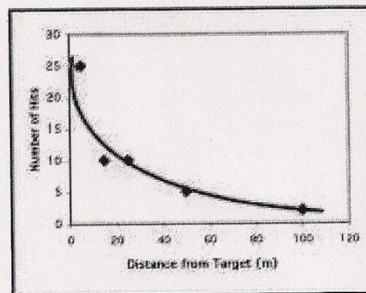
B)



C)



D)



INTEGRATED PROCESS SKILLS TEST II

35. Ann has an aquarium in which she keeps goldfish. She notices that the fish are very active sometimes but not at others. She wonders what affects the activity of the fish. What is a hypothesis she could test about factors that affect the activity of the fish?
- A) The more you feed fish, the larger the fish become.
 - B) The more active the fish, the more food they need.
 - C) The more oxygen in the water, the larger the fish become.
 - D) The more light on the aquarium, the more active the fish.
36. Mr. Bixby has an all electric house and is concerned about his electric bill. He decides to study factors that affect how much electrical energy he uses. Which variable might influence the amount of electrical energy used?
- A) The amount of television the family watches.
 - B) The location of the electric meter.
 - C) The number of baths taken by family members.
 - D) A and C

YOU'RE DONE!

Appendix D: Student's Guide – Computer Simulation

FACULTY OF EDUCATION, UNIVERSITY OF OTTAWA

Inquiry:

Newton's Second Law of Motion

Student's Guide

2010

COMPUTER SIMULATION

Introduction

Student's Guide is a book of learning activities for students who are participating in computer-based simulation group. In this guide, the main learning objective is to develop your understanding of the basic concepts of force and motion and enhance your scientific investigation skills as you progress through.

The learning activities are situated in a learning model known as “5Es Learning Cycle”. The 5Es learning cycle consists of five phases: *engage*, *explore*, *explain*, *elaborate*, and *evaluate*. Thereby, you will have opportunity to design and conduct an investigation to come up with Newton's 2nd law of motion, using different computer-based simulations. The 5Es learning cycle will allow you to work in pairs or small groups to make predictions, discuss procedures and results, resolve difficulties, explain events, and extend your knowledge in new situations.

This book is intended to be your guidelines to complete your tasks; however, beside the computer simulations the teacher can use many other resources, print or non-print, to help you achieve the many stated learning objectives of Ontario Curriculum (Grade 11 – University Preparation).

Safety Guidelines

All activities should not be attempted without the permission and supervision of a teacher.

When special attention to safety is required, an icon like this  appears beside the activity.

In addition to the routine safety procedures used in your school, there are some general guidelines that are important to follow when working through any one of the activities.

When you begin:

- Listen carefully to your teacher's instructions.

- Make sure your teacher knows if you have medical or physical conditions that might affect your ability to carry out activities safely.
- If you wear a hearing aid or contact lenses, tell your teacher before starting any activities.
- Start working on activities only after your teacher tells you to begin.

In the lab

- Make sure long hair or loose clothing is tied back.
- Never eat or drink while you are working.
- Work quietly and carefully with a partner or partners, and pay attention to the actions of others around you as well as your own.
- Inform your teacher immediately of any damaged equipment, any accident, or any behavior that you consider dangerous.

Experiments using computer simulation

- Your computer station and your hands should be dry when in contact with any hardware.
- Always unplug electrical equipment by pulling the plug, not the cord.
- Make sure electrical cords are out of the way so that you or others will not trip over them.
- Ask for help in case the software does not work properly.

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Date:

SECTION 1 • Getting Started

You need to form a 2-member group (unless instructed otherwise). You will work collaboratively with a peer, in one computer station, to complete your tasks. Therefore, feel comfortable to participate effectively.

1.1 Try This Yourself! The Moving Man



EXERCISE CAUTION WHEN
USING COMPUTER

What You Need

“The Moving Man” simulation (it is installed in your computer).

Your Task

Use “The Moving Man” simulation (Figure 1) to be familiar with the main functions and features of the software such as: using click-and-drag option, alternating variables, using control buttons, and showing graphs.

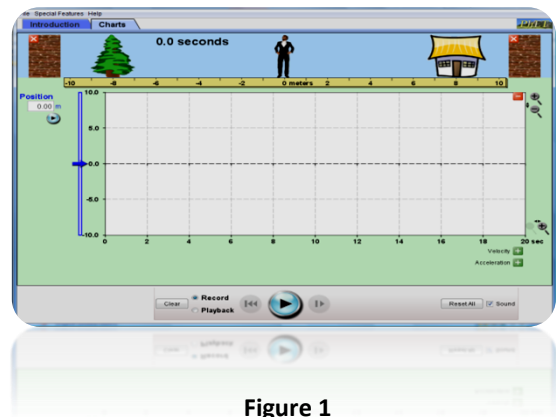


Figure 1

What To Do

1. *Exercise how to change the position of the man!*

First maximize the position graph (x graph).

Then click-and-drag the  up and down (see

Figure 2). Observe the movement of the man.

You can also change the position of the man by giving specific values for X, and then press Enter. Observe the new position of the man.

It is possible to change the maximum range on the graph by clicking on the vertical buttons

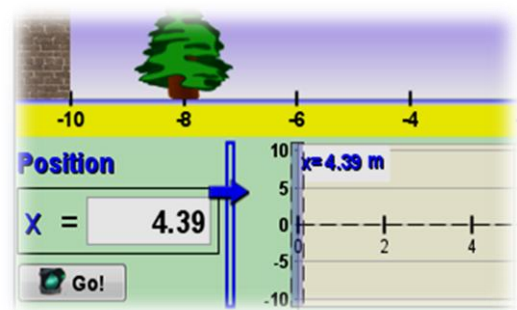


Figure 2

2. *Let the man move!* First, position the man at a point of your choice (as you learned in step 1). Maximize the velocity graph (v graph). Click-and-drag the corresponding  up or down in order to give the man a certain velocity (you can also enter a figure in the space provided). Click on *PLAY* button. Observe the motion of the man. Click on *PUASE* button to stop the clip (Figures 3 a and b).

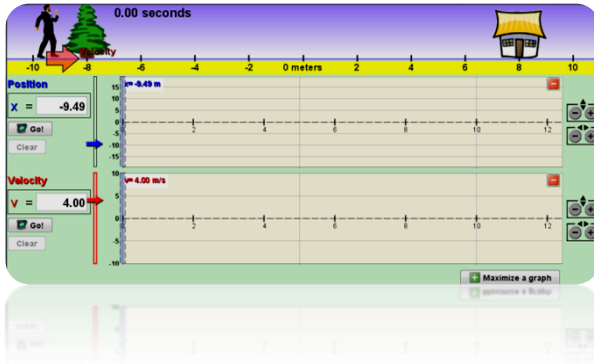


Figure 3 (a)

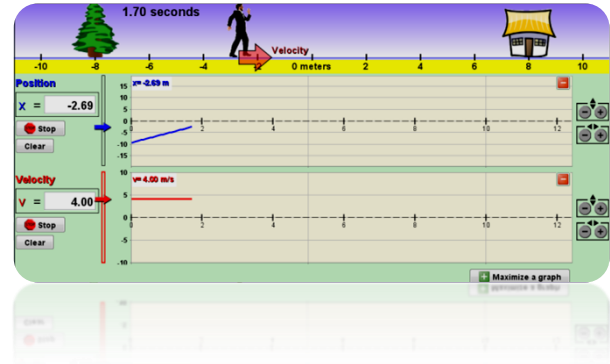


Figure 3 (b)

3. *Repeat* the steps described in sections 1 and 2; using different positions and velocities until you can comfortably observe the man moving across the screen.
4. *Explore* the uses of the following functions (Figure 4):
- Playback
 - Record
 - Rewind
 - Clear
 - Step
 - Slow / Fast

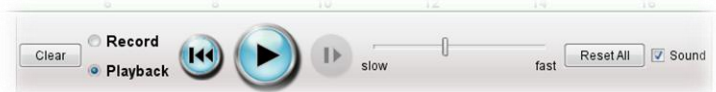


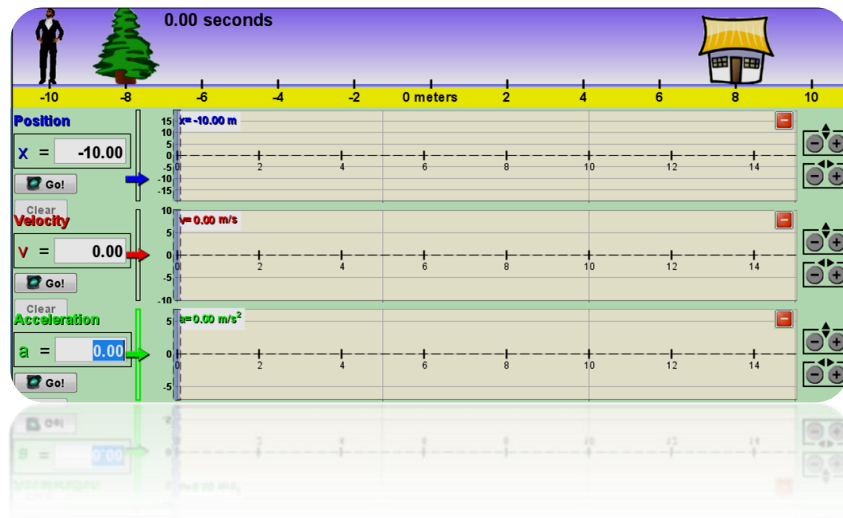
Figure 4

Questions

- In case a line graph goes off the scale, how can you use  buttons to change the range of axis?
- What would you do to clear your data and start over again?
.....
- If you stop a running simulation, how can you restart the same clip again?
.....

4. What velocity makes the man moves from position – 10 m to 10 m in 4.00 seconds? Use the simulation to confirm your answer. Remember, $velocity (v) = \frac{distance (x)}{time (t)}$
-
-
-
5. If you want to make the man run faster and faster (accelerate). Which graph you need to maximize?
6. In the simulation main window (Figure 5), set the man's position at – 10.00 m and velocity at 0.00 m/sec. Try different ways to find an approximate value of acceleration that makes the man moves from – 10 m to 10 m in: 1.0 sec., 3.0 sec., and 8.0 sec. (fill the table below).

Figure 5



Time taken to move the man from – 10 m to 10 m	Approximate value of acceleration
1.0 seconds	
3.0 seconds	
8.0 seconds	

Date:

SECTION 2 . Learning Activities

Now you will start the learning activities. You will be asked to do different types of inquiry tasks: listening to a story, predicting events, designing procedures, conducting investigations using computer simulations, collecting and analyzing data, discussing related issues with peers and/or teacher ...etc. So please listen carefully to your teacher's instructions and enjoy working in your tasks.

2.1 Engage! What is a Force?

Your Task

Read the following story:

On one of January days, the weather was mild but a little bit windy. Christopher went for snow sledding on the Rideau Canal. He chose to sled on the most plane, smooth and newly formed ice. As soon as Christopher sat on the sled, he started moving slowly. In spite of the steady wind, he gradually picked up speed along his way. After short time, his speed became uncontrollable! He panicked ... and did not know what to do, but shouting loudly and said: HELPHELP.



Figure 6

What To Do

1. Discuss with your peer the following questions. It is not necessary to give specific answers, but most importantly reflect on the questions.

- a) Can you tell how did Christopher begin sledding?

.....

- b) What could have happened to Christopher, if the wind blew stronger?

.....

- c) How come! In spite of steady wind, Christopher was sledding faster and faster.

- d) If you were in the Rideau Canal on that day, and Christopher was coming towards you, how could you respond to his call and rescue him?

- e) In contrast, what would be the scenario, if the same events have happened on a plane snow ground?

2. Think of other questions to pose.

.....

3. Share with the class your ideas about the story.

So What is a Force?

Force is always described based on observed effects, that is, a force is described in terms of what it does. A force can set a stationary object into motion; slows it down or speeds it up. This leads to a common definition of force: *A force is a physical quantity that is capable of changing an object's state of motion.* Occasionally, a force may be acting on an object, but its capability to produce a change in motion may be balanced or cancelled by another force or forces so that the net effect is zero.

But! Are there any factors that affecting object's motion, while it is under effect of an external force? If there are, how are these factors related? How can we recognize all forces that are acting on an object?

All these questions and more will be explored and elaborated in the next phases.

2.2 Explore! Force in One Dimension

What You Need

“Force in 1D” simulation (it is installed in your computer).

Your Task

Use “Force in 1D” simulation (Figure 7) to conduct an experiment into the relationships between force, mass, and acceleration.

What To Do

1. *Make a prediction!* See Figure 8. Two damaged cars (1500 kg each) are towed by different vehicles; one is towed by a pickup truck and the other by a motorbike. The pickup truck exerts a stronger pulling on the damaged car than the motorbike.



Figure 8

Compare the motion (change in velocity or acceleration) of the towed cars.

.....

.....

.....

2. *Design procedures to test your prediction!* First, Log on to “Force in 1D” simulation. Maximize “Graph Acceleration”, and choose an object (make your front screen similar to Figure 7).

In your small group, think of procedures to investigate how different applied forces affect the acceleration of an object:

.....

.....

Collect your data in the table blow, and plot a graph of force versus acceleration.



EXERCISE CAUTION WHEN
USING COMPUTER

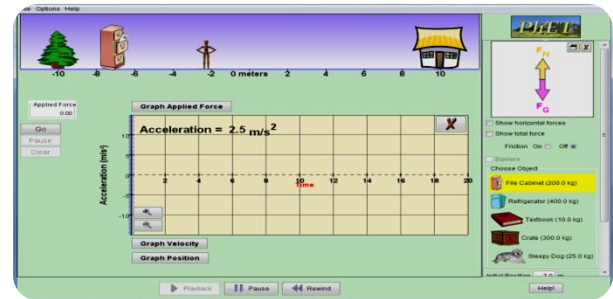
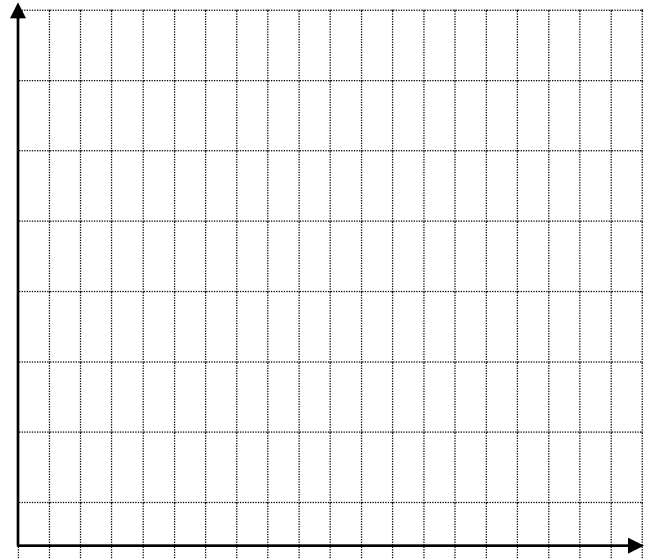


Figure 7

Force (F)	Mass (m)	Acceleration (a)
Newton	kg	m/sec ²



Conclude your result and compare it with the prediction you have made in part 1.

.....

.....

.....

3. *Make another prediction!* See Figure 9. The curling stone used in the Olympic Games weighing around 44 pounds (20 kg). If another stone with a larger mass is used in the game of curling, how the motion (change in velocity or acceleration) of the new curling stones is compared with the old one? Consider the force exerted by average player remains the same with both stones.



Figure 9

.....

.....

.....

.....

4. *Design procedures to test your prediction stated in part 3!*

Stay in “Force in 1D” simulation.

Use other controls such as mass slider (Figure 10), and think of procedures to investigate: how does the acceleration of an object change with different masses?

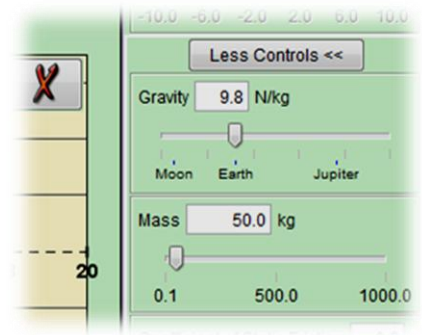


Figure 10

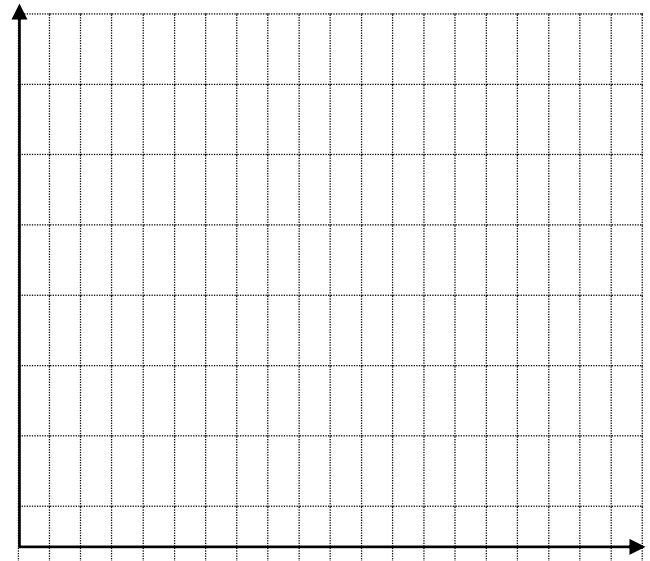
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Collect your data in the table blow, and plot a graph of mass versus acceleration.

Force (F)	Mass (m)	Acceleration (a)
Newton	kg	m/sec ²



Conclude your result and compare it with the prediction you have made in part 3.

.....

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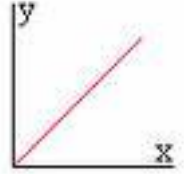
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Questions

1. Referred to the collected data on pages 10 and 11, fill in the following blanks:
 - If the applied force doubles, the acceleration..... for a constant mass.
 - As the mass decreases to one-third, the acceleration for a constant force.

2. If a graph shows a straight line passes through the origin (Figure 11), does the line describe a direct or inverse relationship?

3. Consider the procedures you have designed to investigate how applied force is related to the acceleration for a constant mass (step 2, page 9). Choose the appropriate term that describes force, mass, and acceleration as variables in your experiment.
 - The force is a (control, manipulating, responding) variable.
 - The acceleration is a(control, manipulating, responding) variable.
 - The mass is a(control, manipulating, responding) variable.

Figure 11

What is Next?

You learned from Newton's first law of motion, when the forces acting on an object are balanced, the object will either move continuously at a constant speed or stay at rest. In your *Explore* phase (section 2.2), you tried to recognize two principles: the type of motion occurs when there is a net force acting on an object; and how object with a large mass has more tendencies (resistance) to move than object with less mass, when the same force is applied.

Next, you will try to combine these two principles into a single statement, and state what is known as Newton's second law of motion.

2.3 Explain! Newton's Second Law of Motion



EXERCISE CAUTION WHEN
USING COMPUTER

What You Need

“Force in 1D” simulation (in case you want to confirm ideas or look for more evidence).
Please, join other students and form a 4-member group (as per teacher's instructions).

Your Task

Use your collected data, graphs, and observations obtained in *explore* section to discuss the relationships between net force, mass, and acceleration, and state Newton's second law of motion.

What To Do

1. *Group discussion: relate acceleration and net force for a constant mass!* See Figure 12.

Consider a racing car with its wheels spinning and its tires pushing back on the road as it begins its motion down the track. There is a net force on the forward direction on the racing car. What is the resulting type of motion?



Racing car

Figure 12



Drag-racing car

What about a drag-racing car! It uses a stronger engine that could produce a forward push as three times as in the racing car. What is the resulting type of motion in the drag-racing car, compared to the racing car?

Write a general statement relating the net force acting on and the resulting acceleration. Considering the racing and drag-racing cars (Figure 12) have approximately similar masses.

.....

.....

.....

2. *Group discussion: relate acceleration and mass for a constant force!* See Figure 13.

It is possible to accelerate a baseball in your hand up to large speeds compared to a bowling ball. A professional baseball pitcher can accelerate a baseball from 0 mph to 90 mph before releasing it. Explain, why this is not so with a bowling ball (consider the force exerted by an average healthy person remains constant).

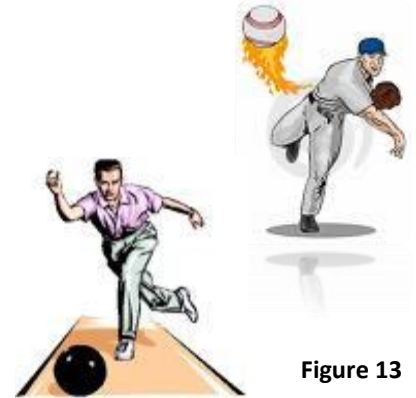


Figure 13

Write a general statement relating the acceleration and mass, when the force acting is constant:.....

3. *Class discussion: state Newton's second law of motion!* (In words and symbols)

Questions

1. A 5 kg block is resting on a frictionless surface is acted on by 12.5 N. What is the acceleration of the block?
.....
2. A student is ten-pin bowling with her friends. She gives a 7.0 kg bowling ball an acceleration 5.0 m/sec^2 . Calculate the net force she exerts on the ball.
.....

Date:

2.4 Try This Yourself! Draw Free Body Diagram



EXERCISE CAUTION WHEN
USING COMPUTER

Background: Force Is a Vector

Force is described by a magnitude and a direction. It therefore is a vector quantity. A force can be represented in a diagram by a directed line segment (an arrow) $\longrightarrow$. The length of the line segment represents the magnitude of the force, and the arrowhead shows its direction.

Free-body diagram (Figure 14) is used to visualize all forces acting on an object. It is convenient to use the free-body diagram to analyze the forces in terms of Newton's law of motion. For example, the free-body diagram of an object moving on a rough surface would show four forces acting on: two equal sized forces (the normal force and the weight), force due to friction, and the applied force (Figure 14).

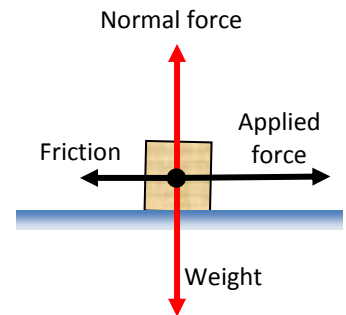


Figure 14

What You Need

“Force in 1D” simulation.

Your Task

Use “Force in 1D” simulation to draw free-body diagram and show all forces acting on an object.

What To Do

1. Log on to “Force in 1D” simulation and do the following:
 - click on Free Body Diagram button to show the mini window (if the diagram is not shown already);
 - make sure the **horizontal forces**, **total force**, and **Friction ON** are ticked (see Figure 15);
 - select an object;



Figure 15

- click-and-drag the object towards the right until it starts moving. Meanwhile observe the Free Body Diagram on the mini window (Figure 16 a);
- release the cursor, and observe the motion of the object (Figure 16 b);
- repeat the above steps using stronger forces (click.....drag.....and release);

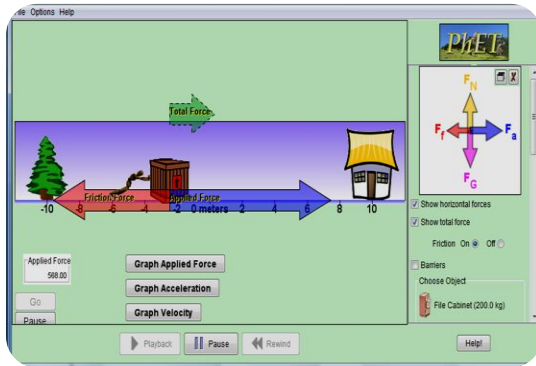


Figure 16 a

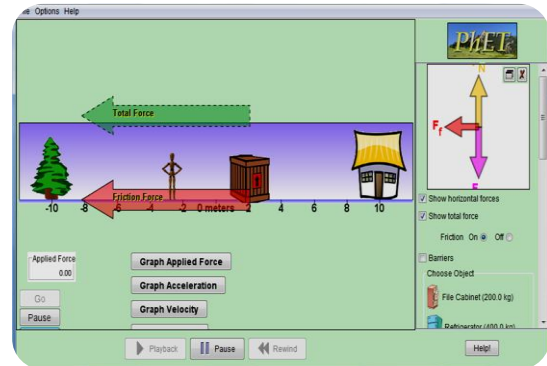


Figure 16 b

2. On the space next to each of the following cases, sketch a free-body-diagram of your object and **label all forces** acting on (Remember! you can always use “Force in 1D” simulation to confirm your answers):

- Before applying a pushing force (object is at rest).

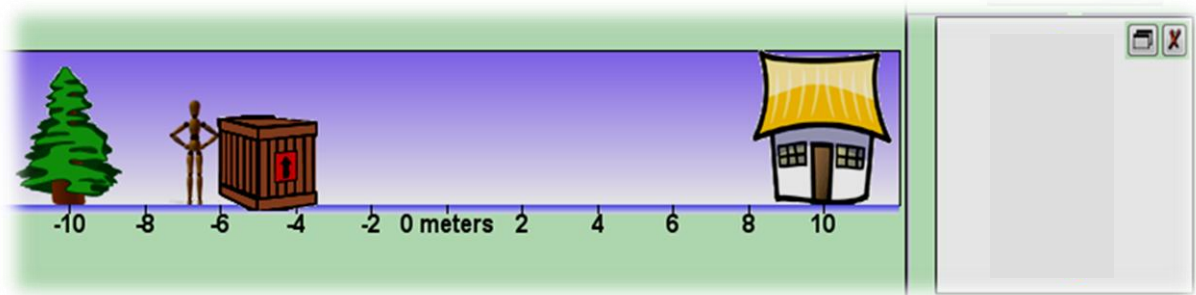


Figure 17

- While applying a pushing force on your object (while dragging)

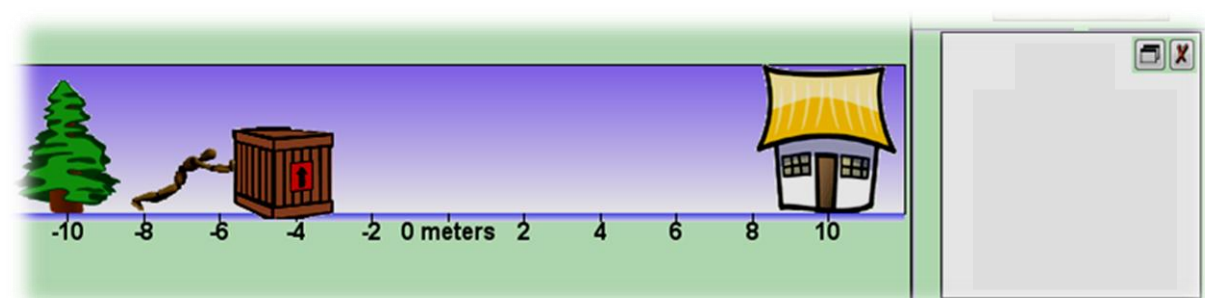


Figure 18

- When the pushing force is released (when you release the cursor)

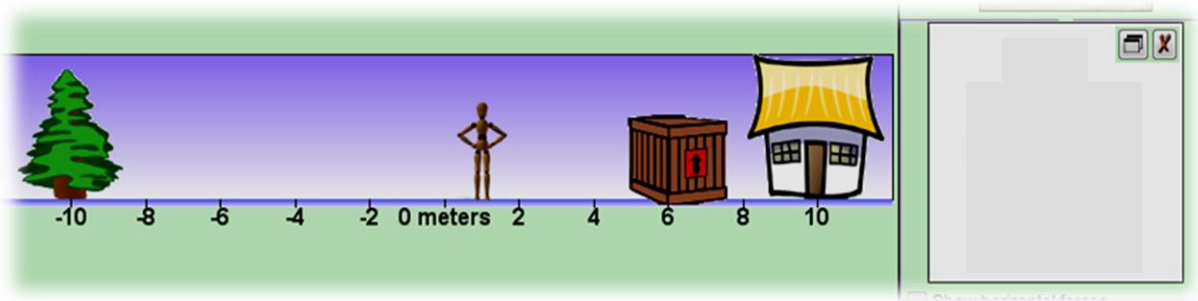


Figure 19

Questions

1. Explain, why an object cannot move a long a rough surface, in spite the force acting on. However, if a stronger force is applied, the object will move.

.....

2. Consider the above activity. When the pushing force is released, what does the friction force do to the object?

.....

3. A book resting on a table has two forces acting on it: its weight and the upward contact force. What makes the book does not move?

.....

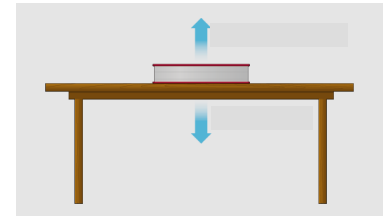


Figure 20

4. Consider a jet plane moving through the air with **constant speed** in a straight line. Figure 21 shows the free-body diagram of the jet plane. Beside the drag and lift forces, name the other two forces acting on the plane. What is the magnitude of the horizontal net force acting on the plane?

.....

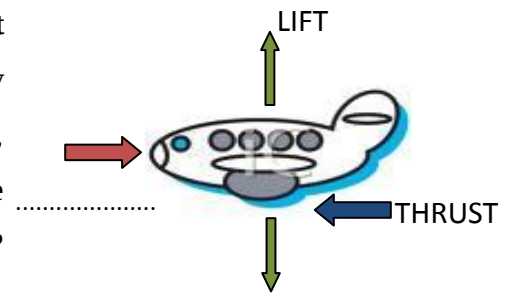


Figure 21

Date:

2.5 Elaborate! Practice Newton's 2nd law

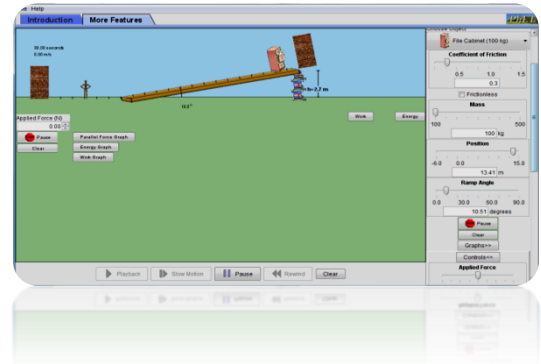
What You Need

“The Ramp” simulation (it will be installed in your computer).

Your Task

Use “The Ramp” simulation (Figure 22) to apply Newton's second law in new situation: motion of an object in an inclined plane.

Figure 22



What To Do

1. *Make a prediction!* See Figure 23. Skiing is one of the popular winter sports in Canada. An athlete is performing a downhill skiing, how do you describe the resulting type of motion at different points?

.....

.....

.....

.....



Figure 23

2. *Test your prediction!* First, Log on to “The Ramp” simulation. Make your front screen similar to Figure 22. Choose your object, tick on frictionless option, and set suitable figures for mass, position, and ramp angle, then click on (Go!) button. Observe and describe the motion of the sliding object.

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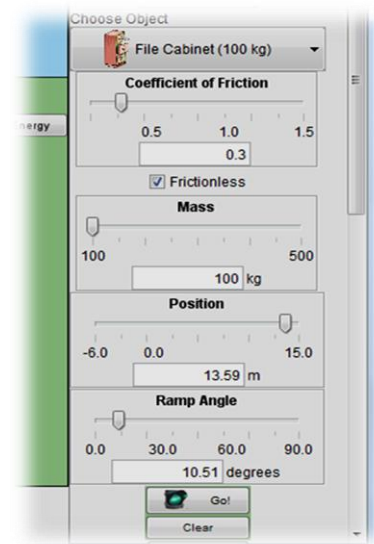


Figure 24

You can make the control buttons shown below (Figure 25) very useful to repeat the motion of your object and have better observation.

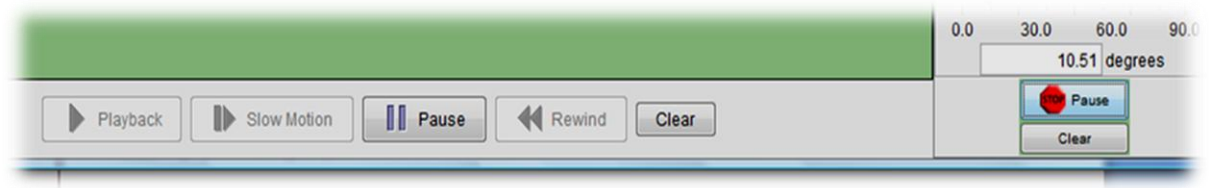


Figure 25

3. *More testing!* Use the control buttons of “The Ramp” simulation (Shown on Figure 24 and Figure 25) to vary the mass of object, ramp angle, and friction of the surface in order to observe the motion of an object in new situations:

- a. how does the acceleration change with different masses?

when the masses are sliding on a frictionless surface.....

.....

.....

when the masses are sliding on a rough surface

.....

.....

- b. how does the motion of the object change with different angles of ramp?

.....

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- c. with or without friction, the object will have a higher acceleration? Explain.

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SECTION 3 • Test Your Knowledge

At this stage you have studied the relationship between force and motion. You investigated the effect of forces in different situations: in straight line, and inclined plane. In the final phase of 5Es learning cycle (*evaluate*), you need to test your knowledge and see how good you are (Remember! you can always use “Force in 1D” or “The Ramp” simulations to confirm your answers).



EXERCISE CAUTION WHEN
USING COMPUTER

3.1 Evaluate! Test Your Knowledge

Questions

1. To pull a single block at a steady speed along the floor requires a force of 2 N. What force will be needed to pull the *three* identical blocks at the same steady speed (See Figure 26).

- a. 2.0 N
- b. 4.0 N
- c. 6.0 N
- d. 8.0 N



Figure 26

2. A body is accelerating if
 - a. it is speeding up
 - b. it is slowing down
 - c. it is changing direction
 - d. all of the above
3. A person applies a force of 15 N (East) on an object of weight 20 N. If the force of friction has a magnitude of 5.0 N, what is the horizontal net force? (Draw free-body diagram to show forces)
 - a. 20.0 N (West)
 - b. 35.0 N (Down)
 - c. 10.0 N (East)
 - d. 25.0 N (Up)

4. Two students, investigating the effect of different forces on the acceleration of different masses, obtained the following data:

Acceleration (m/sec^2)	0	0	0	0	0
Mass (kg)	1.0	2.0	3.0	4.0	5.0

Which statement best describe the data?

- This data does not make any sense
 - The net force in each attempt seems balanced (equal zero).
 - The objects are placed in frictionless surfaces.
 - In each attempt, the friction force is always smaller than the applied force.
5. Two boxes, one of mass 60 kg and the other 90 kg, are in contact and at rest on a smooth surface. An 800 N force is exerted on both boxes together. Calculate the acceleration of both boxes.

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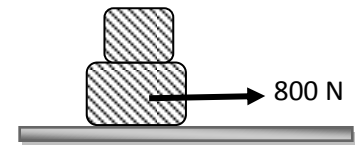


Figure 27

6. A driver turned the engine off and forgot to put the hand-break on. His car started moving downhill as shown in Figure 28. In the space below draw a free-body diagram showing all forces acting on the car.



Figure 28

Appendix E: Student's Guide – Physics Laboratory

FACULTY OF EDUCATION, UNIVERSITY OF OTTAWA

Inquiry: Newton's Second Law of Motion

Student's Guide

2010

PHYSICS LABORATORY

Introduction

Student's Guide is a book of learning activities for students who are participating in concrete phenomena group. In this guide, the main learning objective is to develop your understanding of the basic concepts of force and motion and enhance your scientific investigation skills as you progress through.

The learning activities are situated in a learning model known as “5Es Learning Cycle”. The 5Es learning cycle consists of five phases: *engage*, *explore*, *explain*, *elaborate*, and *evaluate*. Thereby, you will have opportunity to design and conduct an investigation to come up with Newton's 2nd law of motion, using physics laboratory apparatus. The 5Es learning cycle will allow you to work in pairs or small groups to make predictions, discuss procedures and results, resolve difficulties, explain events, and extend your knowledge in new situations.

This book is intended to be your guidelines to complete your tasks; however, beside the laboratory apparatus the teacher can use many other resources, print or non-print, to help you achieve the many stated learning objectives of Ontario Curriculum (Grade 11 – University Preparation).

Safety Guidelines

All activities should not be attempted without the permission and supervision of a teacher.

When special attention to safety is required, an icon like this  appears beside the activity.

In addition to the routine safety procedures used in your school, there are some general guidelines that are important to follow when working through any one of the activities.

When you begin:

- Listen carefully to your teacher's instructions.

- Make sure your teacher knows if you have any other medical or physical conditions that might affect your ability to carry out activities safely.
- If you wear a hearing aid or contact lenses, tell your teacher before starting any activities.
- Start working on activities only after your teacher tells you to begin.

In the lab

- Make sure long hair or loose clothing is tied back.
- Never eat or drink while you are working.
- Work quietly and carefully with a partner or partners, and pay attention to the actions of others around you as well as your own.
- Inform your teacher immediately of any damaged equipment, any accident, or any behavior that you consider dangerous.

Cleanup

- Wash your hands after completing any activity.
- Clean all equipments and put it away according to your teacher's instructions.
- Follow your teacher's instructions for cleaning up spills and disposing of materials.

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Date:

SECTION 1 • Getting Started

You need to form a 2-member group (unless instructed otherwise). You will work collaboratively with a peer, in one station, to complete your tasks. Therefore, feel comfortable to participate effectively.

1.1 Try This Yourself!



EXERCISE CAUTION AT ALL
TIMES

What You Need

Dynamic cart, ruler, ticker-tape timer and related apparatus, known masses, string, pulley, clamp, balance, and stopwatch.

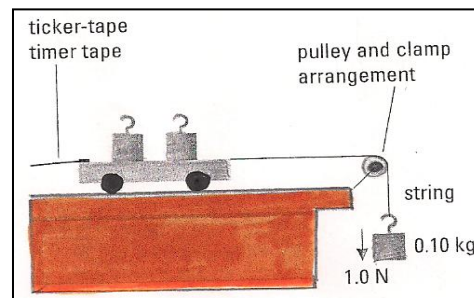
Your Task

What does the motion look like for a cart rolling horizontally in a ramp?

What To Do

1. *Set up the cart!* Set up the apparatus as shown in Figure 1.

Figure 1



2. *Run the cart!* Attach a length of recording tape to the cart. Thread it through the timer. Start the timer and release the vertical mass so that the cart starts moving and the recording tape is pulled through the timer. Repeat this step until you have a clear tape of the motion.
3. *Explore* the uses of the following tools:

- a. Stop watch: run the cart again, and this time use the stopwatch to time the motion of the cart. Compare the time recorded by the stopwatch to the time recorded in the ticker tape you obtained in step 2.

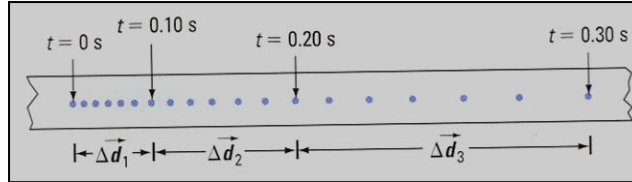


Figure 2

- b. Ruler: use the ruler to measure the distance corresponding to each time interval (See Figure 2).

Question

1. Use the recording timer and a ruler to calculate the average velocity for each time interval as shown on Figure 2. (*average velocity* = $\frac{\text{total distance}}{\text{total time}}$)

.....

.....

.....

2. Use the measurements you obtained in step 3 and find the acceleration of the cart.

.....

.....

.....

Date:

SECTION 2 . Learning Activities

Now you will start the learning activities. You will be asked to do different types of inquiry activities: listening to a story, predicting events, designing procedures, conducting investigations using laboratory equipments, collecting and analyzing data, discussing related issues with peers and/or teacher ...etc. So please listen carefully to your teacher's instructions and enjoy working in your tasks.

2.1 Engage! What is a Force?

Your Task

Read the following story:

*On one of January days, the weather was mild but a little bit windy. Christopher went for snow sledding on the Rideau Canal. He chose to sled on the most plane, smooth and newly formed ice. As soon as Christopher sat on the sled, he started moving slowly. In spite of the steady wind, he gradually picked up speed along his way. After short time, his speed became uncontrollable! He panicked ... and did not know what to do, but shouting loudly and say: **HELP...HELP**.*



Figure 3

What To Do

1. Discuss with your peer the following questions. It is not necessary to give specific answers, but most importantly reflect on the questions.

- a) Can you tell how did Christopher begin sledding?

.....

- b) What could have happened to Christopher, if the wind blew stronger?

.....

- c) How come! In spite of steady wind, Christopher was sledding faster and faster.

.....

- d) If you were in the Rideau Canal on that day and Christopher was coming towards you, how could you respond to his call, and rescue him?
-
-
- e) In contrast, what would be the scenario, if the same events have happened on a plane snow ground?
-
2. Think of other questions to pose.
-
-
-
3. Share with the class your ideas about the story.

So What is a Force?

Force is always described based on observed effects, that is, a force is described in terms of what it does. A force can set a stationary object into motion; slows it down or speeds it up. This leads to a common definition of force: *A force is a physical quantity that is capable of changing an object's state of motion.* Occasionally, a force may be acting on an object, but its capability to produce a change in motion may be balanced or cancelled by another force or forces so that the net effect is zero.

But! Are there any factors that affecting object's motion, while it is under effect of an external force? If there are, how are these factors related? How can we recognize all forces that are acting on an object?

All these questions and more will be explored and elaborated in the next phases.

2.2 Explore! Force in One Dimension



EXERCISE CAUTION AT ALL
TIMES

What You Need

Pulley, ticker-tape timer and related apparatus, string, known masses (or loads), spring scales, ruler, and dynamic cart.

Your Task

Set your apparatus (Figure 4) to design and conduct an experiment into the relationships between force, mass, and acceleration.

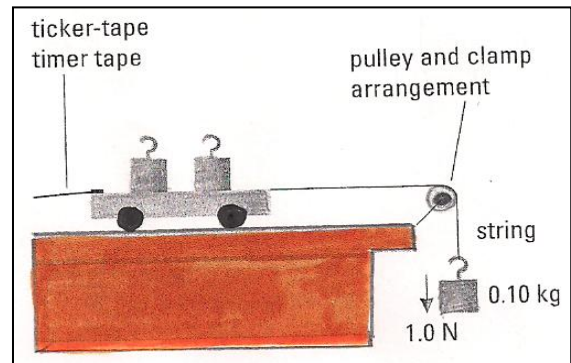


Figure 4

What To Do

1. *Make a prediction!* See Figure 5. Two damaged cars (1500 kg each) are towed by different vehicles; one is towed by a pickup truck and the other by a motorbike. The pickup truck can exert a stronger pulling on the damaged car than the motorbike.



Figure 5

Compare the motion (change in velocity or acceleration) of the towed cars.

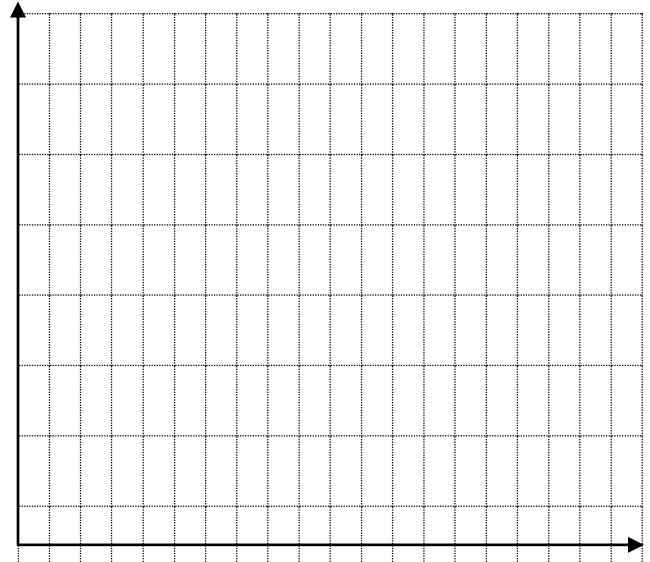
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2. *Design procedures to test your prediction!* First, set up the dynamic cart, vertical mass(es), and as shown in Figure (4). You can use a spring balance to find the unknown masses. In your small group, think of procedures to investigate how different applied forces affect the acceleration of an object:

.....
.....

Collect your data in the table below, and plot a graph of force versus acceleration.

Force (F)	Mass (m)	Acceleration (a)
Newton	kg	m/sec ²



Conclude your result and compare it with the prediction you have made in part 1.

.....

.....

.....

3. *Make another prediction!* See Figure 6. The curling stone used in the Olympic Games weighing around 44 pounds (20 kg). If another stone with a larger mass is used in the game of curling, how the motion (change in velocity or acceleration) of the new curling stones is compared with the old one? Consider the force exerted by average player remains the same with both stones.



Figure 6

.....

.....

.....

.....

4. *Design procedures to test your prediction stated in part 3! Stay at your experimental setup.*

.....

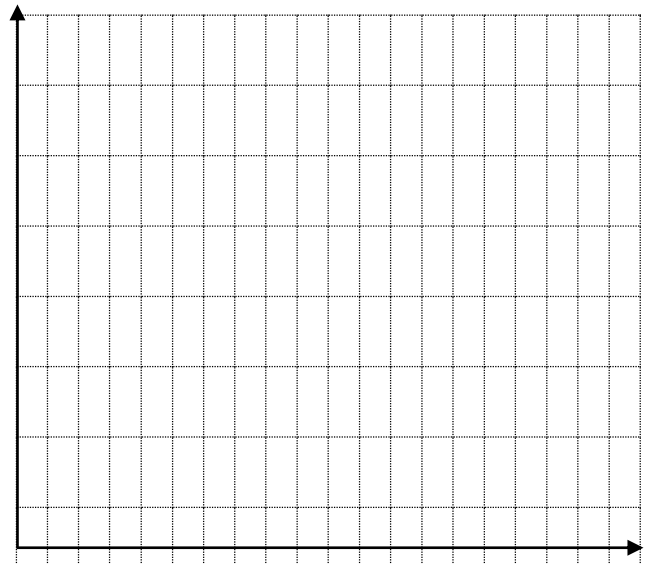
.....

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.....

Collect your data in the table blow, and plot a graph of mass versus acceleration.

Force (F)	Mass (m)	Acceleration (a)
Newton	kg	m/sec ²



Conclude your result and compare it with the prediction you have made in part 3.

.....

.....

.....

.....

Questions

1. Referred to the collected data on pages 9 and 10, fill in the following blanks:
 - a. If the applied force doubles, the acceleration..... for a constant mass.
 - b. As the mass decreases to one-third, the acceleration for a constant force.
2. If a graph shows a straight line passes through the origin (Figure 7), does the line describe a direct or inverse relationship?

 
3. Consider the procedures you have designed to investigate how applied force is related to the acceleration for a constant mass (step 2, page 8). Use the appropriate term that describes force, mass, and acceleration as variables in your experiment.
 - a. The force is a (control, manipulating, responding) variable.
 - b. The acceleration is a(control, manipulating, responding) variable.
 - c. The mass is a(control, manipulating, responding) variable.

Figure 7

What is Next?

You learned from Newton's first law of motion, when the forces acting on an object are balanced, the object will either move continuously at a constant speed or stay at rest. In your *Explore* phase (section 2.2), you tried to recognize two principles: the type of motion occurs when there is a net force acting on an object; and how object with a large mass has more tendencies (resistance) to move, than object with less mass, when the same force is applied.

Next, you will try to combine these two principles into a single statement, and state what is known as Newton's second law of motion.

Date:

2.3 Explain! Newton's Second Law of Motion



EXERCISE CAUTION AT ALL
TIMES

What You Need

Same experimental set up (in case you want to confirm ideas or look for more evidence).
Please, join other students and form a 4-member group (as per teacher's instructions).

Your Task

Use your collected data, graphs, and observations obtained in *explore* section to discuss the relationships between net force, mass, and acceleration, and state Newton's second law of motion.

What To Do

1. *Group discussion: relate acceleration and net force for a constant mass!* See Figure 8.

Consider a racing car with its wheels spinning and its tires pushing back on the road as it begins its motion down the track. There is a net force on the forward direction on the racing car. What is the resulting type of motion?



Racing car

Figure 8



Drag-racing car

What about a drag-racing car! It uses a stronger engine that could produce a forward push as three times as in the racing car. What is the resulting type of motion for the drag-racing car, compared to the racing car?

Write a general statement relating the net force acting on and the resulting acceleration.

Considering the racing and drag-racing cars (Figure 8) have approximately similar masses.

.....

.....

.....

2. *Group discussion: relate acceleration and mass for a constant force!* See Figure 9.

It is possible to accelerate a baseball in your hand up to large speeds compared to a bowling ball. A professional baseball pitcher can accelerate a baseball from 0 mph to 90 mph before releasing it. Explain, why this is not so with a bowling ball (considering the force exerted by an average healthy person remains constant).



Figure 9

Write a general statement relating the acceleration and mass, when the force acting is constant:.....

3. *Class discussion: state Newton's second law of motion!* (In words and symbols)

Questions

1. A 5 kg block is resting on a frictionless surface is acted on by 12.5 N. What is the acceleration of the block?
.....
2. A student is ten-pin bowling with her friends. She gives a 7.0 kg bowling ball an acceleration 5.0 m/sec^2 . Calculate the net force she exerts on the ball.
.....

Date:

2.4 Try This Yourself! Draw Free Body Diagram

Background: Force Is a Vector

Force is described by a magnitude and a direction. It therefore is a vector quantity. A force can be represented in a diagram by a directed line segment (an arrow) $\longrightarrow$. The length of the line segment represents the magnitude of the force, and the arrowhead shows its direction.

Free-body diagram (Figure 10) is used to visualize all forces acting on an object. It is convenient to use the free-body diagram to analyze the forces in terms of Newton's law of motion. For example, the free-body diagram of an object moving on a rough surface would show four forces acting on: two equal sized forces (the normal force and the weight), force due to friction, and the applied force (Figure 10).

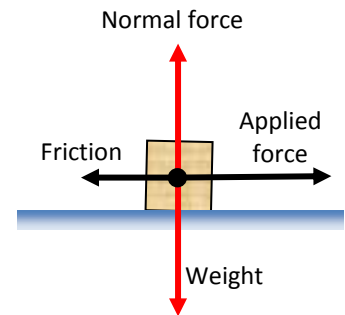


Figure 10

What You Need

Paper and pencil.

Your Task

Draw free-body diagram and show all forces acting on an object.

What To Do

1. *Read* the following strategy to help you draw a free-body diagram:

- draw a sketch of the object isolated from its surrounding;
- locate, with a point, the center of the object;
- from the point, draw line to represent each force acting on the object;
- don't include forces that the object exerts on other objects.

2. Draw free-body-diagrams to show the forces acting in each of the following objects. (**label all forces** acting on the objects)

- A car stays at rest and weighs 10,000 N. A normal force exerted by the ground on the car of 10,000 N (up), and a force of friction exerted by the ground on the tires of 4,000 N (back).



Figure 11

- A swimmer weighs 600 N, exerts a force of 80 N to swim forward. The water opposes the swimmer's motion by a force of 70 N (backward). The water exerts a force of 600 N (up) on the swimmer to keep her floating.



Figure 12

- A skateboarder weighs 400 N, is moving at a steady speed. A force of friction of 500 N (back) at the wheels is balanced by the force the boy applies to move forward. The ground exerts a force on the board of 400 N.



Figure 13

Questions

1. A book resting on a table has two forces acting on it: its weight and the upward contact force. What makes the book does not move?
-

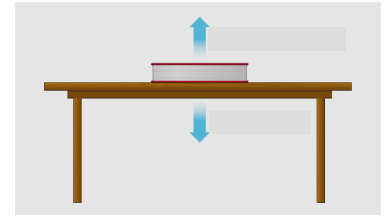


Figure 14

2. Consider a jet plane moving through the air with **constant speed** in a straight line. Figure 15 shows the free-body diagram of the jet plane. Beside the drag and lift forces, name the other two forces acting on the plane. What is the magnitude of the horizontal net force acting on the plane?

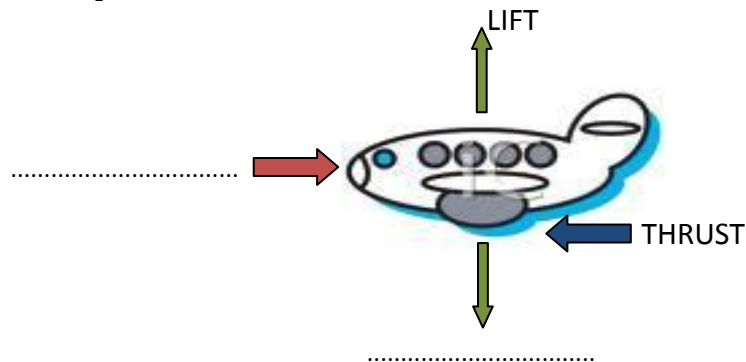


Figure 15

Date:

2.5 Elaborate! Practice Newton's 2nd law



EXERCISE CAUTION AT ALL
TIMES

What You Need

Wood blocks, dynamic cart, ticker-tape timer and related apparatus, protractor, clamp, long ramp, and loads.

Your Task

Apply Newton's second law of motion in new situation: motion of an object in an inclined plane.

What To Do

1. *Make a prediction!* See Figure 16. Skiing is one of the popular winter sports in Canada. An athlete is performing a downhill skiing, how do you describe the resulting type of motion?

.....

.....

.....

.....



Figure 16

2. *Test your prediction!* First, set up the ramp, ticker-tape timer, and the cart as shown in Figure 17. Release the cart down the ramp, and observe the motion. Describe the motion of the sliding cart.

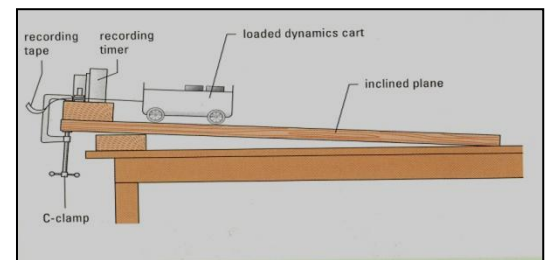


Figure 17

.....

.....

.....

.....

3. *More testing!* Vary the total mass in the cart (by adding more loads), and vary the ramp angle (by changing the angle with the horizontal); and test the following cases:

a. how does the acceleration change with different masses?

when the masses are sliding on a frictionless surface.....

.....

.....

when the masses are sliding on a rough surface

.....

.....

b. how does the motion of the object change with different angles of ramp?

.....

.....

.....

.....

c. with or without friction, the object will have a higher acceleration? Explain.

.....

.....

.....

.....

SECTION 3 • Test Your Knowledge

At this stage you have studied the relationship between force and motion. You investigated the effect of forces in different situations: in straight line, and inclined plane. In the final phase of 5Es learning cycle (*evaluate*), you need to test your knowledge and see how good you are (Remember! you can always use experimental designs to confirm your answers).

3.1 Evaluate! Test Your Knowledge



EXERCISE CAUTION WHEN
USING APPARATUS

Questions

1. To pull a single block at a steady speed along the floor requires a force of 2 N. What force will be needed to pull the *three* identical blocks at the same steady speed (See Figure 18).

- a. 2.0 N
- b. 4.0 N
- c. 6.0 N
- d. 8.0 N



Figure 18

2. A body is accelerating if
 - a. it is speeding up
 - b. it is slowing down
 - c. it is changing direction
 - d. all of the above
3. A person applies a force of 15 N (East) on an object of weight 20 N. If the force of friction has a magnitude of 5.0 N, what is the horizontal net force? (Draw free-body diagram to show forces)
 - a. 20.0 N (West)
 - b. 35.0 N (Down)
 - c. 10.0 N (East)
 - d. 25.0 N (Up)

4. Two students investigating the effect of different forces on the acceleration of different masses obtained the following data:

Acceleration (m/sec^2)	0	0	0	0	0
Mass (kg)	1.0	2.0	3.0	4.0	5.0

Which statement best describe the data?

- This data does not make any sense
 - The net force in each attempt seems balanced (equal zero).
 - The objects are placed in frictionless surfaces.
 - In each attempt, the friction force is always smaller than the applied force.
5. Two boxes, one of mass 60 kg and the other 90 kg, are in contact and at rest on a smooth surface. An 800 N force is exerted on both boxes together. Calculate the acceleration of both boxes.

.....

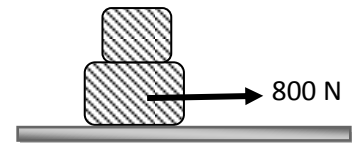


Figure 19

6. A driver forgot to put the hand-break on. His car started moving downhill as shown in Figure 20. In the space below draw a free-body diagram showing all forces acting on the car.



Figure 20

Appendix F: Teacher's Guide – Computer Simulation

FACULTY OF EDUCATION, UNIVERSITY OF OTTAWA

Inquiry:

Newton's Second Law of Motion

Teacher's Guide

2010

COMPUTER-BASED SIMULATION

The teacher's guide will project the teaching strategy and procedures as expected to happen in computer-based simulation environment. The guide includes: teaching and learning objectives, description of the learning environments, and 5Es learning cycle activities.

Learning objectives and expectations

Science as Inquiry overall expectations:

Students are expected to:

1. analyze and propose improvements to technologies that apply concepts related to dynamics and Newton's laws, and assess the technologies' social and environmental impact;
2. investigate, in qualitative and quantitative terms, net force, acceleration, and mass and solve related problems;
3. demonstrate an understanding of the relationship between changes in velocity and unbalanced forces in one dimension;

(Source: p. 186 - 187, Ontario Curriculum, Grade 11 – University Preparation, 2009).

Teaching objectives

The teaching objectives will be set to help students grasp the fundamental concepts of Newton's second law of motion and be able to apply these concepts in new situations. The teaching objectives will primarily be looking at ways to foster the development of students' communication and inquiry skills. To do that, you are expected to:

1. set expectations for laboratory management, disciplines, and routines;
2. establish and maintain healthy and safe learning environment;
3. implement 5Es learning cycle (engage, explore, explain, elaborate and evaluate) as a model for learning and teaching through inquiry;
4. assess students learning as well as the whole class;
5. use multiple methods to measure students' performance and understanding; and
6. provide, as a facilitator, all students with the time, space and resources needed for learning.
7. You might want to do all the activities before the students attempt them.

Learning activities

The learning activities are situated in a learning model known as “5Es Learning Cycle”. The 5Es learning cycle consists of five phases: *engage*, *explore*, *explain*, *elaborate*, and *evaluate*. These phases are basically embedding all aspects of science as inquiry process, tasks, and skills; and students will have the opportunity to use computer simulation to design and conduct an investigation to come up with Newton’s 2nd law of motion. The 5Es learning cycle will allow students to work in pairs or small groups to make predictions, discuss procedures and results, resolve difficulties, analyze and explain events, and extend their knowledge in new situations.

Engage phase is a very short phase of the 5Es learning cycle. You will use a story telling (as an advance organizer) to tell a scenario of a man went for snow sledding on the Rideau Canal. The story is aimed to elicit responses that uncover what students know or think about how force is related to motion of object.

In *explore* phase, students will make predictions, and set procedures to test these predictions. They will use “Force in 1D” simulation in small groups (2 members) to collect data and make observations. You are expected to guide students throughout this phase to accomplish their tasks (as described in the Student’s Guide).

Students will begin to analyze their gathered data in *explain* phase. This is a very important phase, in which students will recap their experiences from exploration phase to state Newton’s second law of motion, in words and symbols. Thus, students need to do thorough discussions with their peers and the teacher. Special attention is needed to help struggling students to achieve their tasks.

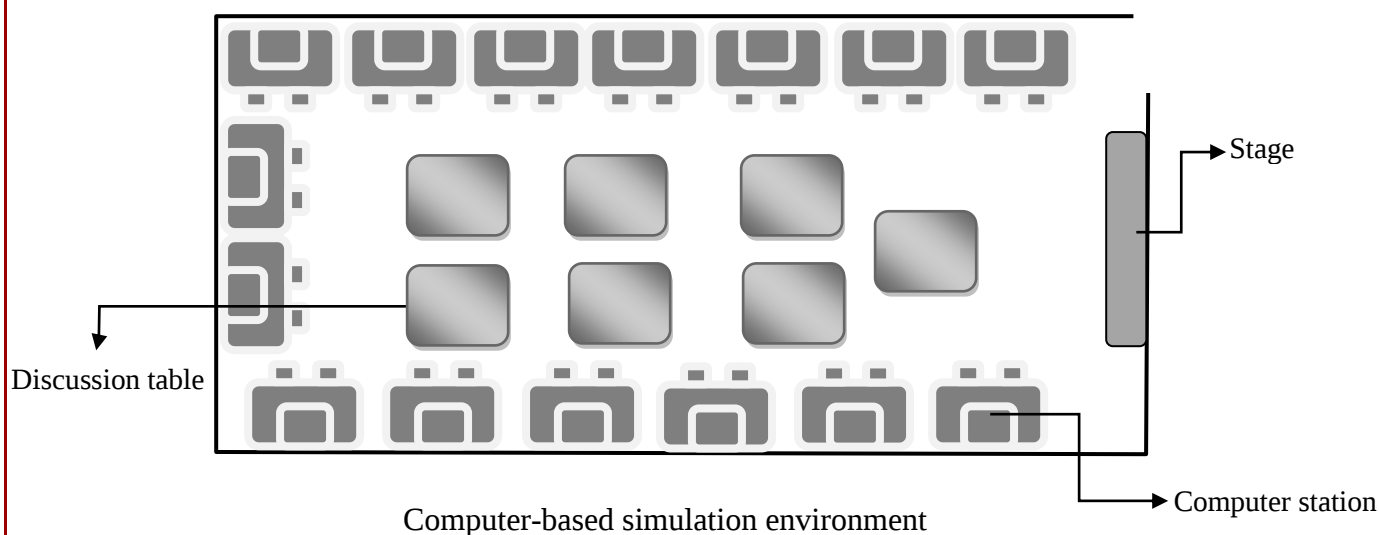
Elaborate phase will transfer students’ learning into new situations. Students will extend their understanding and apply Newton’s second law to real life situation: motion of an object in an inclined plane. In small groups (2 members), students will use another computer simulation to recognize the motion in inclined plane. With your scaffolding, students can, qualitatively, describe the type of resulting motion of an object in an inclined plane, and relate its motion to other factors such as ramp angle, mass, and smoothness of the surface.

In the 5Es learning cycle, assessment information is gathered through ongoing (formative) and end of lesson (summative) assessments. In the formative assessment, you will be observing students as they progress in their activities. Different assessment instruments such as: self

assessment rubric, group assessment rubric, and student progress sheet can be used to help you *evaluate* students' achievements.

Computer-based simulation environment

There will be desk-top computer stations positioned along the sides of the classroom. Each station will accommodate two students. Discussion tables could also be used and distributed in the classroom as shown below.



Other forms of settings could also be used.

Importance of Safety

It is important that students continually show they have the knowledge and skills to safely participate in physics and technology activities. The students can do this by:

- maintaining a well-organized and uncluttered work place;
- following established safely procedures in Student's Guide;
- identifying possible safety concerns;
- carefully following the instructions for the activities given in Student's Guide or by a teacher;
- consistently showing concern for their own safety and that of others.

Getting Started • Training Session (20 minutes)

The students will explore “The Moving Man” computer simulation.

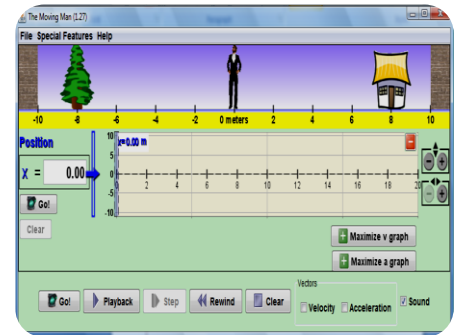
Specific Expectations

By the end of this session, students will:

- recognize the main features and functions of the computer simulation;
- show fluent experience on the uses of the control buttons of the simulation.

Background Information

“The Moving Man” is a computer-based simulation. It simulates the motion of a man in a straight line. It describes position, velocity, and acceleration graphs simultaneously. Different variables can be used to create different situations such as: motion at a constant speed, or acceleration.



Procedures

1. This investigation is ideal for group work (2 members per group).
2. Encourage students to log on to “The Moving Man” simulation to exercise how to:
 - a. change the position of the man using the appropriate buttons;
 - b. let the man move along a straight line;
 - c. manipulate the man’s velocity and acceleration using the appropriate features.
3. Have the students solve the given questions (pages 5-6, Student’s Guide) for more practice.

Challenges

1. Students need to have enough time to gain good experience. They could be encouraged to explore the simulation using different ways.
2. A multimedia projector can be used to show the simulation on a front screen, and facilitate how to resolve common difficulties.
3. Use “The Moving Man” simulation yourself to test out any potential difficulties for your class.

5Es Learning Activities • Engage (5 minutes)

The students will listen to a story-telling about force and motion.

Specific Expectations

By the end of this phase, students will:

- use appropriate terminology related to forces, including, but not limited to: *mass, time, speed, velocity, acceleration, and friction*;

Background Information

The story-telling describes the experience of a man went for snow sledding on the Rideau Canal. The man has faced an unexpected situation. A small and steady pushing force exerted by the wind made him accelerate regularly in a straight line.



Procedures

1. This investigation is ideal for group work (2 members per group).
2. Ask the groups to think about why Christopher picked up more speed?
3. Recap the whole story with students and discuss with the class any further questions.
4. Explain the concept of force and define it as a physical quantity that is capable of changing an object's motion (page 8).

Challenges

In this phase, the students should **not** be given definitions or answers. They will explore their questions in the next phase.

Assessment

The class discussion will show whether the student is able to use appropriate terminology to describe various types of motion.

5Es Learning Activities • Explore (20 minutes)

The students will explore force in one dimension.

Specific Expectations

By the end of this phase, students will:

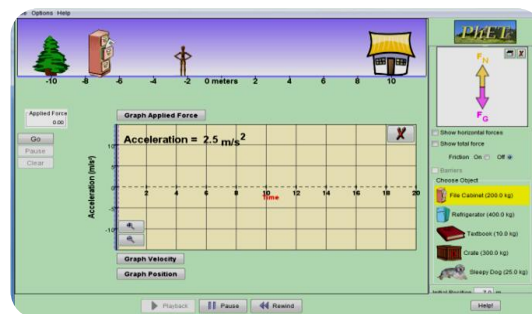
- make predictions to relate between force, mass, and acceleration;
- plan and conduct an inquiry into the relationships between the acceleration of an object and its net force and mass, and report the resulting data.

Background Information

Two types of relationships are introduced in this investigation: the relationship between net force and acceleration for a constant mass; and the relationship between acceleration and mass for a constant force. An unbalanced net force is directly proportional to accelerate; and for a constant force a massive object will acceleration in a lower rate than a less mass object.

Procedures

1. This investigation is ideal for group work (2 members per group).
2. Ask students to make two predictions using their **own words** to relate between net force and acceleration when the mass is constant, and then between acceleration and mass when the force is kept constant.
3. Have students use “Force in 1D” simulation to manipulate variables and test their predictions.
 - a. First prediction: how does the acceleration of an object under the influence of various applied forces change?
 - b. Second prediction: how does the acceleration of different masses under the influence of a constant net force change?



4. Students should tabulate their data, plot graphs, and draw conclusions. Students should always check their measurements and accuracy.
5. Encourage students to use scientific terms such as **directly proportional and inversely proportional** when drawing conclusions (page 10 and 11 Student's Guide).
6. Have students solve questions 1-3 (page 12, Student's Guide).

Challenges

1. Allow students to resolve their difficulties in their own, and provide guidance whenever necessary. More attention should be drawn while solving questions 1-3 (page 12).
2. Encourage student to work in their groups.
3. Provide sufficient time for students to puzzle through the problem.

Assessment

The following checklist can be used to record whether the students can make predictions, plan procedures, and conduct the inquiry. Level 1 indicates that the students have successfully completed their task.

Performance Category	Level 1	Level 2	Level 3	Level 4
Make prediction				
Plan procedures				
Test predictions				

5Es Learning Activities • Explain (30 minutes)

The students will state Newton's second law of motion.

Specific Expectations

By the end of this phase, students will:

- use appropriate terminology related to forces, including, but not limited to: *mass, time, speed, velocity, acceleration, friction, gravity, normal force, and free-body diagrams*;
- state Newton's second law of motion, and apply them, in qualitative terms, to explain the effect of forces acting on objects;
- analyze the relationships between acceleration and applied forces such as the force of gravity, normal force, force of friction ...etc, and solve related problems involving forces in one dimension, using free-body diagrams and algebraic equations;

Background Information

According to Newton's first law, when the forces acting on an object are balanced, the object either continues to move at a constant velocity or remains at rest. However, an object will accelerate (speed up, slow down, or change direction) if there is a net force acting on. The later is known as Newton's second law of motion ($F = ma$).

To better visualize all forces acting on an object, we draw a free-body diagram. It is convenient and instructive to use the free-body diagram to analyze the forces in terms of Newton's laws of motion, and give qualitative descriptions to the motion of the object and the forces causing it.

Procedures

1. This session is ideal for group work (4 members per group), and class discussion.
2. You may have to help the students to gather evidences to explain the events that have been conducted in explore phase.
3. Encourage the students to carefully read **What To Do** section in their guides and come up with general statements (pages 13-14, Student's Guide).

4. Discuss with the whole class their statements.
5. State Newton's second law of motion ($F = ma$) using appropriate terms. State the force is measured in Newton (N), the mass is measured in kilogram (kg), and the acceleration is measured in m/sec^2 .
6. Have the students to solve questions 1-2 (pages 14 and 17, Student's Guide).
7. Encourage the students to use "Force in 1D" to draw and label all forces on free-body diagram (as requested on pages 16 and 17, Student's Guide).

Challenges

Remember! The students can revisit their computer simulation over and over, and at any time, to confirm evidences or repeat procedures.

Assessment

The responses of student in the guide (pages 13, 14, 16, & 17) will show whether he/she is able to analyze the given situations and conclude scientifically acceptable statements.

5Es Learning Activities • Elaborate (20 minutes)

The students will apply Newton's second law of motion in new situation: motion in an inclined plane.

Specific Expectations

By the end of this lesson, students will conduct an inquiry to analyze, in qualitative terms, the forces acting on an object, and use free-body diagrams to calculate the net force and the acceleration of an object.

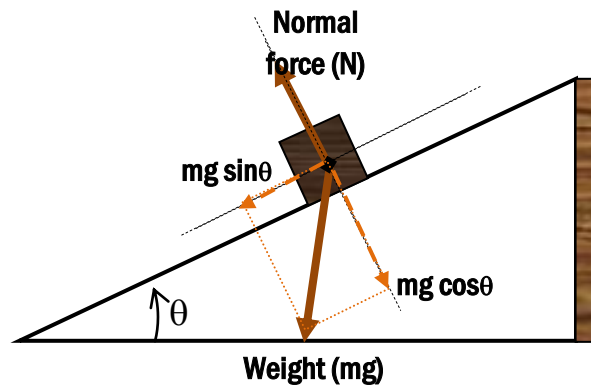
Background Information

An object placed on a frictionless inclined plane will often slide down the surface. The rate at which the object slides down the surface is dependent upon the ramp angle; the greater the

angle, the faster the rate at which the object will slide. According to Newton's second law of motion, objects accelerate down inclined planes because of unbalanced force acting parallel to the plane. To understand this type of motion, it is important to analyze the forces acting on an object in an inclined plane. In a frictionless plane, the only force acting parallel to the plane is the component of the weight, which causing the object to accelerate downhill. However, in a rough surface, a friction will oppose the object's motion and reduce the rate of increasing speed.

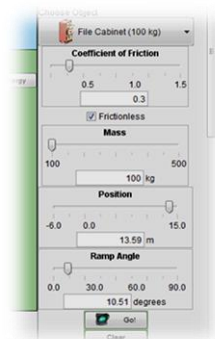
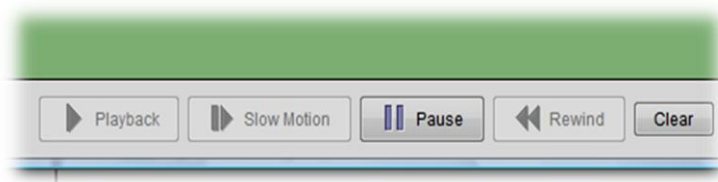
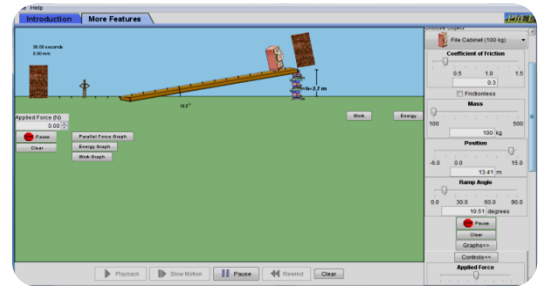
Figure 21

A free-body-diagram shows the weight of the object and its components, and the normal force.



Procedures

1. This investigation is ideal for group work (2 members per group).
2. Ask students to describe the resulting type of motion of an athlete who is performing downhill skiing.
3. Have students use “The Ramp” simulation to confirm their descriptions.
4. Help students to design procedures aiming to relate the motion of an object in an inclined plane to mass, ramp angle, and smoothness of the plane.
5. Provide guidance to assist students work through “The Ramp” simulation by recalling the uses of the control buttons shown below.



Challenges

1. Always suggest to students to draw free-body diagram to analyze forces acting on an object.
2. Demonstrate how to use the control buttons of the simulation, if needed.

Assessment

The student answers to questions 1-6 (pages 20 & 21) will show whether he/she is able to apply Newton's second law of motion in new situations.

5Es Learning Activities • Evaluate

The following assessment rubrics can be used as part of your summative assessment.

Self-Assessment Rubric

	I will do this next time	I can do better	I was good at this	I did very well
1. Follow instructions	1	2	3	4
2. I asked questions when I did not understand	1	2	3	4
3. I worked well in my group	1	2	3	4
4. I respected the contributions of others and did not put them down	1	2	3	4
5. What did I learn from this investigation?				
.....				
6. What did I have trouble with?				

.....

7. How did I contribute to the success of the group?

.....

8. I could do better at:

.....

9. I was best at:

.....

Group Assessment Rubric

	I will do this next time	I can do better	I was good at this	I did very well
1. We prepared for the investigation.	1	2	3	4
2. We carried out our plans	1	2	3	4
3. We listened to each other's ideas and suggestions.	1	2	3	4
4. We worked out our problems together.	1	2	3	4
5. The biggest problem in the group was:				
.....				
6. Our group was best at:				
.....				
7. We could do better at				
.....				
8. Our group would like to learn more about:				
.....				

Appendix G: Teacher's Guide – Physics Laboratory

FACULTY OF EDUCATION, UNIVERSITY OF OTTAWA

Inquiry:

Newton's Second Law of Motion

Teacher's Guide

2010

PHYSICS LABORATORY

The teacher's guide will project the teaching strategy and procedures as expected to happen in a concrete phenomenon environment. The guide includes: teaching and learning objectives, description of the learning environments, and 5Es learning cycle activities.

Learning objectives and expectations

Science as Inquiry overall expectations:

Students are expected to:

4. analyze and propose improvements to technologies that apply concepts related to dynamics and Newton's laws, and assess the technologies' social and environmental impact;
5. investigate, in qualitative and quantitative terms, net force, acceleration, and mass and solve related problems;
6. demonstrate an understanding of the relationship between changes in velocity and unbalanced forces in one dimension;

(Source: p. 186 - 187, Ontario Curriculum, Grade 11 – University Preparation, 2008).

Teaching objectives

The teaching objectives will be set to help students grasp the fundamental concepts of Newton's second law of motion and be able to apply these concepts in new situations. The teaching objectives will primarily be looking at ways to foster the development of students' communication and inquiry skills. To do that, you are expected to:

1. set expectations for laboratory management, disciplines, routines and grading procedures;
2. establish and maintain healthy and safe learning environment;
3. implement 5Es learning cycle (engage, explore, explain, elaborate and evaluate) as a model for learning and teaching through inquiry;
4. assess students learning as well as the whole class;
5. use multiple methods to measure students' performance and understanding;
6. provide, as a facilitator, all students with the time, space and resources needed for learning.
7. You might want to do all the activities before the students attempt them.

Learning activities

The learning activities are situated in a learning model known as “5Es Learning Cycle”. The 5Es learning cycle consists of five phases: *engage*, *explore*, *explain*, *elaborate*, and *evaluate*. These phases are basically embedding all aspects of science as inquiry process, tasks, and skills; and students will have the opportunity to use the appropriate apparatus to design and conduct an investigation to come up with Newton’s 2nd law of motion. The 5Es learning cycle will allow students to work in pairs or small groups to make predictions, discuss procedures and results, resolve difficulties, analyze and explain events, and extend their knowledge in new situations.

Engage phase is a very short phase of the 5Es learning cycle. You will use a story telling (as an advance organizer) to tell a scenario of a man went for snow sledding on the Rideau Canal. The story is aimed to elicit responses that uncover what students know or think about how force is related to motion of object.

In *explore* phase, students will make predictions, and set procedures to test these predictions. They will design experimental setup in small groups (2 members) to collect data and make observations. You are expected to guide students throughout this phase to accomplish their tasks (as described in the Student’s Guide).

Students will begin to analyze their gathered data in *explain* phase. This is a very important phase, in which students will recap their experiences from exploration phase to state Newton’s second law of motion, in words and symbols. Thus, students need to do thorough discussions with their peers and the teacher. Special attention is needed to help struggling students to achieve their tasks.

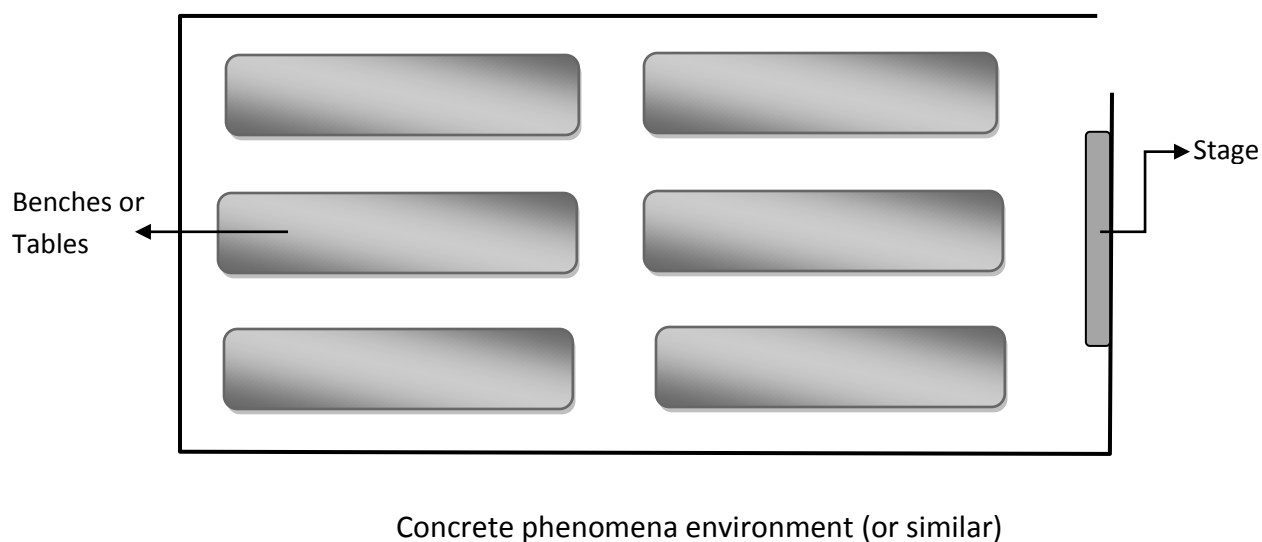
Elaborate phase will transfer students’ learning into new situations. Students will extend their understanding and apply Newton’s second law to real life situation: motion of an object in an inclined plane. In small groups (2 members), students will design another experimental setup to recognize the motion in inclined plane. With your scaffolding, students can, qualitatively, describe the type of resulting motion of an object in an inclined plane, and relate its motion to other factors such as ramp angle, mass, and smoothness of the surface.

In the 5Es learning cycle, assessment information is gathered through ongoing (formative) and end of lesson (summative) assessments. In the formative assessment, you will be observing students as they progress in their activities. Different assessment instruments such as: self

assessment rubric, group assessment rubric, and student progress sheet can be used to help you *evaluate* students' achievements.

Physics laboratory environment:

There will be benches or stations positioned as per your physics laboratory settings. Each station will accommodate two students, and can be used to hold discussion periods as well.



Other forms of setting can also be used.

Importance of Safety

It is important that students continually show they have the knowledge and skills to safely participate in physics laboratory activities. The students can do this by:

- maintaining a well-organized and uncluttered work place;
- following established safely procedures in Student's Guide;
- identifying possible safety concerns;
- carefully following the instructions for the activities given in Student's Guide or by a teacher;
- consistently showing concern for their own safety and that of others.

Getting Started • Training Session (20 minutes)

The students will explore their concrete subjects (apparatus).

Specific Expectations

By the end of this session, students will:

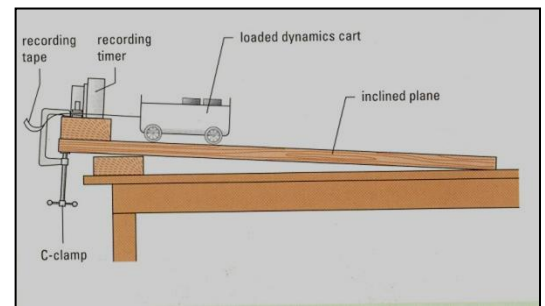
- recognize how to set up an experiment using: ramp, C-clamp, trolley, and a power supply;
- practice how to measure time and length with acceptable precision.

Background Information

In this activity, students will study quantitatively the motion of a trolley that has been released from the top of a ramp. In this case, the trolley will start moving from rest and gradually pick up speed along the way. The shape of velocity-time graph will be a straight line passes through the origin and shows steady increase of the velocity with respect to time.

Procedures

1. This investigation is ideal for group work (2 members per group).
2. Encourage students to use the given apparatus to:
 - a. set up the ramp, recording timer, and trolley, as shown in the figure;
 - b. attach a length of recording tape to the trolley and thread it through the timer;
 - c. start the timer and release the trolley down the ramp (as described in the Student's Guide).
3. Have the students solve the given question (page 5, Student's Guide) for more practice.



Challenges

1. Students need to have enough time gain good experience. They could be encouraged to explore how to set up the apparatus using different ways.
2. A multimedia projector can be used to show how such apparatus can be used.
3. Try to do the experiment yourself to test out any potential difficulties for your class.

5Es Learning Activities • Engage (5 minutes)

The students will listen to a story-telling about force and motion.

Specific Expectations

By the end of this phase, students will:

- use appropriate terminology related to forces, including, but not limited to: *mass, time, speed, velocity, acceleration, and friction*;

Background Information

The story-telling describes the experience of a man went for snow sledding on the Rideau Canal. The man has faced an unexpected situation. A small and steady pushing force exerted by the wind made him accelerate regularly in a straight line.



Procedures

1. This investigation is ideal for group work (2 members per group).
2. Ask the groups to think about the reasons that made Christopher picked up speed.
3. Have the students to think of other questions about the story and share them with the class.

Challenges

In this phase, the students should **not** be given definitions or answers. They will explore their questions in the next phase.

Assessment

The class discussion will show whether the student is able to use appropriate terminology to describe various types of motion.

5Es Learning Activities • Explore (20 minutes)

The students will explore force in one dimension.

Specific Expectations

By the end of this phase, students will:

- make predictions to relate between force, mass, and acceleration;
- plan and conduct an inquiry into the relationship between the acceleration of an object and its net force and mass, and report the resulting data.

Background Information

Two types of relationships are introduced in this investigation: the relationship between net force and acceleration for a constant mass; and the relationship between acceleration and mass for a constant force. An unbalanced net force is directly proportional to accelerate; and for a constant force a massive object will acceleration in a lower rate than a less mass object.

Procedures

1. This investigation is ideal for group work (2 members per group).
2. Ask students to make two predictions to relate: first between net force and acceleration, and then mass and acceleration.
3. Have students use their apparatus to test their predictions.
 - a. First prediction: how does the acceleration of an object under the influence of various applied forces change?
 - b. Second prediction: how does the acceleration of different masses under the influence of a constant net force change?
4. Students should tabulate their data, plot graphs, and draw conclusions.
5. Have students to solve the questions 1-3 (page 11, Student's Guide).

Challenges

1. Allow students to resolve their difficulties in their own, and provide guidance whenever necessary. More attention should be drawn while solving questions 1-3 (page 11)

2. Encourage student to work in their groups.
3. Provide sufficient time for students to puzzle through the problem.

Assessment

The following checklist can be used to record whether the students can make predictions, plan procedures, and conduct inquiry. Level 1 indicates that the students have successfully completed their task.

Performance Category	Level 1	Level 2	Level 3	Level 4
Make prediction				
Plan procedures				
Test predictions				

5Es Learning Activities • Explain (30 minutes)

The students will state Newton's second law of motion.

Specific Expectations

By the end of this phase, students will:

- use appropriate terminology related to forces, including, but not limited to: *mass, time, speed, velocity, acceleration, friction, gravity, normal force, and free-body diagrams*;
- state Newton's second law of motion, and apply them, in qualitative terms, to explain the effect of forces acting on objects;
- analyze the relationships between acceleration and applied forces such as the force of gravity, normal force, force of friction ...etc, and solve related problems involving forces in one dimension, using free-body diagrams and algebraic equations;

Background Information

According to Newton's first law, when the forces acting on an object are balanced, the object either continues to move at a constant velocity or remains at rest. However, an object will accelerate (speed up, slow down, or change direction) if there is a net force acting on. The later is known as Newton's second law of motion ($F = ma$).

To better visualize all forces acting on an object, we draw a free-body diagram. It is convenient and instructive to use the free-body diagram to analyze the forces in terms of Newton's laws of motion, and give qualitative descriptions to the motion of the object and the forces causing it.

Procedures

1. This session is ideal for group work (4 members per group), and class discussion.
2. You may have to help the students to gather evidences to explain the events that have been conducted in explore phase.
3. Encourage the students to carefully read **What To Do** section in their guides and come up with general statements (pages 12-13, Student's Guide).
4. Discuss with the whole class their statements.
5. State Newton's second law of motion ($F = ma$). State that the force is measured in Newton (N), the mass is measured in kilogram (kg), and the acceleration is measured in m/sec^2 .
6. Have the students to solve questions 1-2 (pages 13 and 16, Student's Guide).
7. Encourage the students to label all forces on free-body diagram of objects (as requested on page 15, Student's Guide).

Challenges

Remember! The students can visit their experimental set up, at any time, to confirm evidences or repeat procedures.

Assessment

The responses of student in the guide (pages 12, 13, 15 & 16) will show whether he/she is able to analyze the given situations and conclude scientifically acceptable statements.

5Es Learning Activities • Elaborate (20 minutes)

The students will apply Newton's second law of motion in new situation: motion in an inclined plane.

Specific Expectations

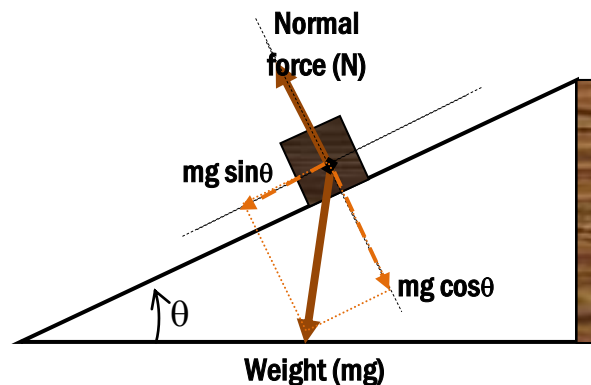
By the end of this lesson, students will conduct an inquiry to analyze, in qualitative terms, the forces acting on an object, and use free-body diagrams to calculate the net force and the acceleration of an object.

Background Information

An object placed on a frictionless inclined plane will often slide down the surface. The rate at which the object slides down the surface is dependent upon the ramp angle; the greater the angle, the faster the rate at which the object will slide. According to Newton's second law of motion, objects accelerate down inclined planes because of unbalanced force acting parallel to the plane. To understand this type of motion, it is important to analyze the forces acting on an object in an inclined plane. In a frictionless plane, the only force that is acting parallel to the plane is the component of the weight, which causing the object to accelerate downhill.

Figure 21

A free-body-diagram shows the weight of the object and its components, and the normal force.



Procedures

1. This investigation is ideal for group work (2 members per group).
2. Ask students to describe the resulting type of motion of an athlete who is performing downhill skiing.

3. Have students use their apparatus confirm their descriptions (as described in the Student's Guide).
4. Help students to design procedures aiming to relate the motion of an object in an inclined plane to mass, ramp angle, and smoothness of the plane.
5. Provide guidance to assist students work through their experimental set up.

Challenges

1. Always suggest to students to draw free-body diagram to analyze forces acting on an object.

Assessment

The student answers to questions 1-6 (pages 19 & 20) will show whether he/she is able to apply Newton's second law of motion in new situations.

5Es Learning Activities • Evaluate

The following assessment rubrics can be used as part of your summative assessment.

Self-Assessment Rubric

	I will do this next time	I can do better	I was good at this	I did very well
1. Follow instructions	1	2	3	4
2. I asked questions when I did not understand	1	2	3	4
3. I worked well in my group	1	2	3	4
4. I respected the contributions of others and did not put them down	1	2	3	4

5. What did I learn from this investigation?

.....

6. What did I have trouble with?

.....

7. How did I contribute to the success of the group?

.....

8. I could do better at:

.....

9. I was best at:

.....

Group Assessment Rubric

	I will do this next time	I can do better	I was good at this	I did very well
1. We prepared for the investigation.	1	2	3	4
2. We carried out our plans	1	2	3	4
3. We listened to each other's ideas and suggestions.	1	2	3	4
4. We worked out our problems together.	1	2	3	4
5. The biggest problem in the group was:				
.....				
6. Our group was best at:				
.....				
7. We could do better at				
.....				
8. Our group would like to learn more about:				
.....				