

WHAT ARE THE EFFECTS OF COMPUTER SIMULATIONS ON STUDENTS'
CONCEPTUAL UNDERSTANDING OF NEWTONIAN MECHANICS?

by

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DEDICATION

I dedicate this paper to my wife Theresa who has been very supportive and encouraging through this whole process and has given me the best gift in the world, our son Kingston.

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ABSTRACT

Computer simulations provide an interactive and visual environment that promote and support conceptual change in physics education. They are tools that enable students to become actively engaged in their learning and encourage concept exploration and assist in developing their inquiry skills. One area that students consistently retain misconceptions is that of their understanding of Newtonian mechanics and the application of his three laws to motion problems. It is through the implementation of a series of inquiry based student activities that these simulations will be evaluated for their effectiveness in improving conceptual understanding. The study used both qualitative and quantitative methods including summative exams, class observations, student surveys and interviews.

INTRODUCTION AND BACKGROUND

Project Background

Teaching and Classroom Environment

September 2007 saw the implementation of a new program of studies for Physics 20 and 30 in the province of Alberta. This new program introduced a whole new set of verbs in the learner outcomes that indicate the depth of understanding that students completing the course should have. According to Pankratz (2011), “some of the verbs such as *list*, *identify*, *state*, or *define* denote tasks that are very cognitively easy; while other verbs such as *explain*, *evaluate* and *assess* denote tasks that are very cognitively challenging” (p. 1) for the students. Classifying these verbs according to Bloom’s taxonomy reveal that more of the student learner outcomes fall under the classification of comprehension, application and higher mental activities (HMA) as opposed to knowledge based learner outcomes prevalent in the old program of studies. This shift requires students to communicate their understanding of concepts and the relationships between ideas at a deeper conceptual level demonstrating “flexibility and creativity when solving problems” (Pankratz, 2011, p. 1) in order to achieve the standard of excellence.

One area that has been a challenge for students to achieve the standard of excellence in this new program, are the outcomes covered in the dynamics unit. This unit requires students to study the main concepts of Newtonian mechanics such as the three laws of motion, static and kinetic friction and the law of universal gravitation. Many of the concepts and skills learned in this unit provide a solid foundation for enabling success

in the Physics 20 and 30 program of studies. Most of these concepts are familiar to students yet many students harbour misconceptions that inhibit their full understanding of the science behind these topics. The purpose of this research is to assist students in visualizing and overcoming these misconceptions behind Newtonian mechanics by employing the simulations designed by PhET, ExploreLearning and Alberta Education in order to evaluate their effectiveness in improving a students' conceptual understanding and equipping them with the necessary tools to engage them at a higher cognitive level.

Focus Questions

What are the effects of computer simulations on students' conceptual understanding of Newtonian mechanics?

How will the use of computer simulations effect student achievement of learner outcomes related to Newtonian mechanics?

How do computer simulations influence student attitudes towards active inquiry and problem solving?

School Demographics

Students involved in this study attend Salisbury Composite High School in Sherwood Park, Alberta, Canada a suburb of Edmonton, Alberta that has a population of approximately 62,000 people. According to the 2011 school database Salisbury has an enrollment of 1100 students of predominantly Caucasian youth with 95% completing their graduation requirements. According to the Fraser Institute, an independent non-partisan research and educational organization based in Canada, Salisbury is academically ranked 144th out of 276 high schools in Alberta.

Although there is a limited amount of ethnic diversity many of the families that live in the area are socioeconomically advantaged and well educated. According to Statistics Canada (2006), Sherwood Park residents have a median household income of \$102,004 and an average income of \$109,770 with 55.3 per cent of residents ages 15 and older have some post secondary education. As a result, there are high expectations placed on the students academically and a large percentage go on to further their studies at post-secondary institutions.

CONCEPTUAL FRAMEWORK

There are many researchers (Van Heuvelen, 2001; Zollman, 1996) that argue traditional physics instruction does not result in a coherent and consistent conceptual framework for students and results in gross misconceptions and lack of understanding. According to Kelly et al. (2008), “learning is often reduced to student passivity while the teacher becomes the content messenger, pouring knowledge into the empty vessel (p. 2).” The work of McDermott (2001) and the Physics Education Group have outlined several research-based generalizations on the effect of traditional based instruction and student learning and have concluded that teaching by telling is extremely ineffective. In addition to, McDermott also outlined research-based teaching strategies that include methods in which teachers must expose students to the material in multiple contexts, have students participate in the process of constructing qualitative models and provide activities that are intellectually active in order to develop a functional understanding.

Since students have their own understandings and views of the world, there are

preconceptions and scientific misconceptions that conflict with science taught in the classroom (Yip, 1998). Constructivist views suggest that in order to eliminate these misconceptions and for conceptual change to occur students must be confronted with a discrepant event that conflicts with their world-view (Piaget, 1985). This conflict produces a “disequilibrium or cognitive conflict” (p. 618) that allows the student to reflect on what happens and as a result create new knowledge (Zacharia et al., 2003). Longfield (2009) defines a discrepant science event as an event that “vividly portrays an abstract concept that has an unexpected outcome” (p. 266).

One engaging classroom approach that has gained momentum and favor in the literature is the use of computer simulations to teach physics. Simulations are powerful tools that have valuable educational potential to help students understand scientific concepts and assist in promoting conceptual change (Adams, Reid, LeMaster, McKagan, Perkins, Dubson & Wieman, 2008). One group based out of the University of Colorado have collaborated on the Physics Education Technology (PhET) Project which has designed 18 research-based computer simulations to help improve the learning of physics by allowing students to build mental models and intuition about these topics. These simulations allow students to make predictions, manipulate parameters, set variables and immediately visualize the results of these changes (Wieman, Perkins & Adams, 2008). This “engaged exploration” promotes students to pose questions and actively seek the answers by observing the results of their own interaction (Adams et al., 2008), all characteristics of constructivist and inquiry-based learning.

It is this constructivist approach that Zhou, Brouwer, Nocente, & Martin (2005) argue must be used in order to facilitate and enhance conceptual learning through

computer-based applets. This study integrated quantitative and qualitative methods including tests, surveys, class observations and interviews to evaluate the effectiveness of computer simulations. They discovered that although they helped improve conceptual understanding, these simulations should be used in a constructivist teaching environment to be more effective. Blake and Scanlon (2007) also argue that successful technology integration for science teaching is dependent on how the teacher mediated the use of resources, in this case how and what simulations are used. They reveal that “simulations do not work on their own, there needs to be some structuring of the students’ interactions with the simulation to increase effectiveness” (p. 492).

The benefits of computer simulations in assisting with a students’ understanding of physics is well documented in the literature. In 2001, Jimoyiannis and Komis conducted a study on two groups of 15-16 year olds to investigate how computer simulations affected the understanding of velocity and acceleration in projectile motion. The study found that 60% of the experimental group answered three qualitative questionnaire tasks with effectual answers as opposed to only 30% of the control group after using the simulations. An effectual answer was an answer that was not only correct for the question posed but included a thorough explanation and thus understanding. A study by Bayrak (2008) concluded that students in the experiment group who were exposed to computer assisted instruction were more successful than the control group students who were exposed to face-to-face instruction. This study was used to research the effect of computer simulations in student learning of geometric optics. These are just two examples that suggest a positive correlation between student achievement and the use of computer simulations in improving physics understanding. Zacharias and Anderson

(2003) attribute the success of these simulations to the fact that they empower students, provide unique instructional capabilities, and develop cognitive, manipulative, investigative and communicative skills.

Other research has, however, demonstrated that the use of simulations does not result in a significant change in student achievement. A study by Steinberg (2000) compared a simulation on air resistance to paper and pencil activities in an introductory university physics tutorial. The findings revealed that student performance on a common exam question did not show any significant difference in achievement. Similar conclusions were also found in a study by Kelly, Bradley and Gratch (2008) which compared simulations with equipment based laboratory investigations. Students in this study participated in twelve laboratory experiences of which six consisted of either simulation or equipment investigations. The data used to make the comparisons were graded pre and post-lab reports and the findings suggested that when compared, achievement on these reports were not significantly different. However studies did show that simulations did not hinder a students' understanding and the despite the results the authors argued that simulations are beneficial if used properly and effectively.

In a 2010 paper by Wieman, Adams, Loeblein and Perkins outline eight strategies for using simulations effectively. These include: defining specific learning goals; encourage students to use sense-making and reasoning; connect with and build on students' prior knowledge and understanding (including addressing possible misconceptions); connect to and make sense of real-world experiences; encourage productive collaborative activities; do not overly constrain student exploration; require reasoning/sense-making in words and diagrams (i.e. multiple representations); help

students monitor their understanding (p. 1).

With these eight strategies in mind they highlight many different ways of incorporating the use of simulations in the classroom including lecture, group, lab and homework activities. It is stressed that the simulations need to be “carefully integrated into the curriculum with appropriate activities created around them (p. 5).” One format that may be adopted for this study is to employ a predict-test-confirm group activity approach by giving the students a sequence of challenging questions related to the simulation that they must work through.

Computer simulations provide an interactive, engaging and visual environment that promotes and supports conceptual understanding. Student learners can manipulate parameters, and construct new meaning based on the results of these manipulations if used in a constructivist method. This construction of new knowledge results in higher achievement and deeper conceptual understanding by enabling the student to form connections and relationships between ideas and concepts.

METHODOLOGY

My action research took place over a period of approximately five weeks in which students were investigating the topics of dynamics including Newton’s three laws and his law of universal gravitation. More specifically there were two general outcomes in this unit which included explaining the effects of balanced and unbalanced forces on velocity and explaining that gravitational effects extend throughout the universe. The unit requires students to apply and explain, qualitatively and quantitatively, Newton’s laws to

various motion-type problems as well as describe, qualitatively and quantitatively, Newton's law of gravitation.

Traditionally the students have been taught these concepts with the teacher researcher providing examples and problem solving techniques using a lecture-based instructional model. The main goals of this study were to supplement the teacher-led approach to inquiry activities using computer simulations in order to evaluate the use of these simulations on student comprehension, achievement, engagement and attitude. More specifically the primary question I attempted to address was:

What are the effects of computer simulations on students' conceptual understanding of Newtonian mechanics?

One of the effects I focused on in this study was how the use of these simulations affected student achievement on a common summative assessment and whether or not these simulations had an influence on a students' attitude towards the learning objectives and problem solving.

Participants

In order to gauge the effectiveness of this implementation two study groups were required. The 1st class used in this study was a grade 11 physics class with 26 students, 8 females and 18 males that served as control group and was taught using the traditional approach, that is, no intervention. The 2nd class used in the study was also a grade 11 physics class, which consisted of 23 students, 5 females and 18 males. This second group was subjected to the use of computer simulations in achieving student curricular outcomes. In order to verify whether or not these two groups were comparable a

common non-intervention exam focused on mathematical skills necessary for success in physics such as metric conversions, algebra and graphing skills. This exam (Appendix A) was given after the first week of review instruction on the above topics. The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained.

Data Collection

Over the course of the study there were a total of six simulations used by all students in the study group. Each simulation that was chosen targeted various program outcomes: Simulation 1: Vector Addition involved vector addition in one and two dimensions (Appendix C), Simulation 2: Fletcher's Trolley explored the relationship between force, mass and acceleration (Appendix D), Simulation 3: Atwood Machine applied Newton's second law to pulleys (Appendix E), Simulation 4: Inclined Plane (Frictionless) focused on components of gravitational force and the relationship to normal force (Appendix F), Simulation 5: Friction looked at the difference between kinetic and static forces (Appendix G) and Simulation 6: Gravitational Force investigated the relationship between mass, distance and gravitational force (Appendix H).

The simulations were web-based programs used from a variety of sources such as the PhET group, ExploreLearning Gizmos and Alberta Education. They were carefully picked to correlate with the specific learner outcomes of the dynamics unit and for their interactive nature. The treatment implemented involved having the students complete a guided inquiry-based activity for each simulation that had them either collect and analyze data, compare simulation results to theoretical predictions, describe and explain the cause

and effect of manipulation of the simulation or to assist and verify quantitative calculations. For example, the Atwood Machine activity had students predict the direction of one of the masses, gather data on fall times, analyze this data by calculating acceleration rates, explaining why and how fall times change due to mass differences. The activity acknowledges numerous cognitive tasks described by the various program outcome verbs.

The data collected was used to make comparisons on student achievement and understanding between using simulations versus no simulations on summative quizzes and exams. Data collection techniques are summarized in table 1. The unit was divided into three sections corresponding to the three general outcomes: vector addition in one and two dimensions, balanced and unbalanced forces on velocity, and gravitational forces and fields. After the completion of all the unit program outcomes students completed a common summative unit exam.

Prior to the intervention implementation students were asked to complete the Colorado Learning Attitudes about Science Survey CLASS (Appendix B). This was completed pre-study and post-study to compare the student attitudes towards physics before and after using computer simulations to achieve program outcomes. Student interviews were also conducted after the completion of each simulation to determine their attitudes towards and evaluate the effectiveness of the simulations.

Table 1
Data Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3
<i>Primary Question:</i> 1. What are the effects of computer simulations on students' conceptual understanding of Newtonian mechanics?	Common summative unit assessment (semester 1:2011 compared to semester 2:2012)	Common quiz assessments (semester 1:2011 compared to semester 2:2012)	Interviews
<i>Secondary Questions:</i> 2. How will the use of computer simulations affect student achievement of learner outcomes related to Newtonian dynamics?	Common summative unit assessment (semester 1:2011 compared to semester 2:2012)	Common quiz assessments (semester 1:2011 compared to semester 2:2012)	
3. How do computer simulations influence student attitudes towards active inquiry and problem solving?	CLASS Survey (pre and post unit)	Instructor observations and journaling	Interviews

Summative Review Exam

The summative review exam was an instrument used to determine whether the two groups were comparable. The instrument contains seven questions of varying length that assess the understanding of the skills necessary for student success in physics that were covered in the first week of instruction. These topics include equation manipulation, unit conversions, graphing skills and calculations involving significant digit rules and.

Colorado Learning Attitudes about Science Survey (CLASS)

The Colorado Learning Attitudes about Science Survey is a fairly new instrument designed to measure student attitudes and beliefs about physics and learning physics by researchers at the University of Colorado. According to Adams et al. (2005), the reliability and validity of the survey has been investigated by analyses of over 5000 responses. The instrument consists of 42 statements and a Likert 5-point (strongly agree to strongly disagree) scale to provide insight into student beliefs and attitudes about physics. Although researchers have identified eight thematic categories within the 42 statements, each statement was compared individually as opposed to categorically for this study. The survey was used to compare student attitudes in a grade eleven physics class before and after a unit on Newtonian mechanics that used computer simulations to assist students in achieving the learner outcomes.

Summative Quizzes

Students were evaluated on three of the main topics in this unit which include vector addition, Newton's laws and gravitational forces and fields. The vector addition quiz (Appendix I) consisted of three questions that assessed the students' conceptual understanding and skills regarding vector addition. The Newton's Laws quiz (Appendix J) evaluated students on their understanding of inertia, static and kinetic energy and their ability to apply Newton's three laws quantitatively and qualitatively. The third quiz (Appendix K) assessed students understanding of the inverse square relationship and one dimensional vector analysis of gravitational forces and fields.

Summative Unit Exam

The unit exam (Appendix L) was used to assess whether or not the study intervention had an effect on student achievement and was given to both the study and control classes after the completion of general outcomes B1 and B2 of the Physics 20-30 Alberta Program of Studies. This exam consisted of 16 multiple choice questions, 5 numerical response questions and 5 written response questions.

Student Interviews

Students were interviewed using a written questionnaire (Appendix M) to gain a deeper understanding and insight into their thoughts and attitudes regarding the use of the computer simulations in achieving program outcomes. All students in the class were provided the interview-questionnaire after the completion of the unit but only 15 students of 22 chose to complete it.

Reflective Journal

A reflective journal was used by the instructor to monitor the perception of how each lesson went. Observations were made of students while they completed their inquiry activities in the computer lab and recorded in this journal.

DATA AND ANALYSIS

In order to determine the effect computer simulations had on student achievement, conceptual understanding, and student attitudes towards physics this study collected qualitative and quantitative data from a variety of sources. These sources included pre and post unit surveys, student interviews, summative quiz and summative exam scores. This data was collected from two sets of classes, Group One was taught using a traditional lecture-based approach during semester one and Group Two was taught

traditionally but supplemented heavily with inquiry activities using computer simulations during semester two. In total, there were 49 participants in this study. The researcher determined statistical significance using the statistical analysis software GraphPad to conduct t tests, and measures of variability and central tendency.

Comparison of Group One and Group Two's Summative Review Exam

In order to measure the comparability of the two physics classes, a common summative review exam was administered after a one week review of scientific mathematics topics such as graphing skills and significant digits rules. The control group had a Mean score of 76.13% with a Standard Deviation of 11.08. The intervention group had a Mean score of 79.50% with a Standard Deviation of 10.17. The difference between these two groups were not significant, $t(43) = 1.0617$, $p = 0.2943$. It can be concluded then that the two groups are comparable when determining the effect of using computer simulations.

Comparison of Group One and Group Two's summative evaluation of the Dynamics unit of study

After the conclusion of each general outcome in the dynamics unit group one and two both completed the same summative quiz. These quizzes assessed all levels of cognitive expectations and can be found in the appendices.

Summative Vector Quiz

The next set of data analysis compared Group One and Group Two's summative vector addition quiz after the completion of vector addition outcomes. Group Two used a vector addition simulation to introduce the topics of vector addition in one dimension

and two dimensions to assist in the visualization of these topics. The control group had a Mean score of 74.16% with a Standard Deviation of 15.75. The intervention group had a Mean score of 84.59% with a Standard Deviation of 15.78. The difference between these two groups were statistically significant, $t(45) = 2.2639$, $p = 0.0284$.

Summative Newton's Laws Quiz

The next set of data analysis compared Group One and Group Two's summative Newton's laws quiz after the completion of the general outcome: students will explain the effects of balanced and unbalanced forces on velocity. Group Two used four of the six simulations to assist in the exploration of these Newtonian mechanics topics. The control group had a Mean score of 58.65% with a Standard Deviation of 13.84. The intervention group had a Mean score of 82.05% with a Standard Deviation of 9.83. The difference between these two groups were statistically significant, $t(46) = 6.6332$, $p = 0.0001$.

Summative Gravitational Forces and Fields Quiz

The next set of data analysis compared Group One and Group Two's summative gravitational forces and fields quiz after the completion of the general outcome: students will explain that gravitational effects extend throughout the universe. Group Two used one of the six simulations to assist in the exploration of these outcomes. The control group had a Mean score of 64.96% with a Standard Deviation of 16.90. The intervention group had a Mean score of 81.09% with a Standard Deviation of 14.62. The difference between these two groups were statistically significant, $t(47) = 3.5497$, $p = 0.0009$.

Summative Dynamics Unit Exam

The last set of quantitative data analysis compared Group One and Group Two's summative dynamics unit exam after the completion of all unit program outcomes. Group Two had their instruction supplemented with the use of six simulations while Group One did not. The control group had a Mean score of 58.28% with a Standard Deviation of 13.24. The intervention group had a Mean score of 79.39% with a Standard Deviation of 9.44. The difference between these two groups were statistically significant, $t(46) = 6.3108$, $p = 0.0001$.

Conceptual Understanding and Achievement Analysis

According to the quantitative and qualitative data collected the use of computer simulations had an overwhelming positive effect and influence on student understanding and achievement. This was best demonstrated by student performance on the Newton's Laws Quiz and the Gravitational Forces and Fields Quiz. All the questions on these quizzes were written response format and required the students to explain their answers unlike the Dynamics Unit Exam where the majority of questions were multiple choice, making it more difficult to evaluate conceptual understanding. The class mean of Group Two, those that used the simulations, were an 82% compared to a mean of 58% of Group One and the t -test performed showed that the difference between the means was statistically significant.

Two of the eleven interview questions given to the study group were used to determine whether the simulations assisted in their understanding of the material. The first question asked if the simulation helped the students visualize the ideas and concepts of Newtonian mechanics and of the 15 respondents 73% indicated that the simulations did help "by showing the situation" and it was easier to use the simulations than try and

recreate the situations in the lab.” The second question related to this asked for students to describe how the simulations affected their understanding of the concepts and 80% responded that they improved their ability to visualize the scenario and understand the concepts because “when I changed certain things (parameters) I saw what that would potentially do to the answer” thus clearly revealing the cause and effect nature of the simulations.

Student reasons as for why and how the simulations had an effect on their understanding were very similar in nature. A large number of responses cited that the “visuals allowed me to understand better” and that they “helped to show what was happening and why it was happening.” One of the visible strengths of the simulations were to provide this visual reinforcement and actually “show the situation” as opposed to a traditional lecture approach where visualization tends to be a barrier for students in physics.

Attitude Data Analysis

The computer simulations did have an influence on student attitudes towards active inquiry and problem solving according to the student interview/questionnaires. Of the 11 questions asked in the interview/survey a total of 3 questions related to student attitudes regarding the use of simulations in assisting them with their problem solving skills. These included asking about the enjoyment of using the simulations, whether or not they would use them outside of class and if they would like to use more simulations in class.

When asked if they enjoyed learning the physics concepts using the simulations, 73% agreed that they were enjoyable with comments such as “they provided great examples” and they were good for “the visual students.” They agreed that the simulations helped them understand the concepts and liked “doing something different.” The reasons the students gave for not enjoying the simulations included comments such as they “found it way more useful when the teacher taught in front of the class” and “I find it easier by being taught and using a pen and paper.”

It was interesting to note that when asked whether or not they would use simulations to help them understand and solve problems outside of class only 20% said they would. Reasons included, “I lose focus on the computer” and “I would rather just refer to my notes or textbook to help me.” Yet 73% of the students would be willing to ‘do’ more physics using the computer simulations if done in-class with one student commenting that “simulations are very helpful when paired with an in-class lesson of the concept.”

The CLASS Survey pre- and post-intervention seemed to reveal that overall simulations did not have a significant impact and influence on student attitudes about physics. Of the forty two statements asked in the survey only six of them had a significant change in the average response as summarized in Table 2.

Table 2
CLASS Survey Statements and percentage of responses pre- and post-intervention
 (N=23)

CLASS Survey Statement	Percentages of Responses pre-intervention	Percentages of Responses post-intervention
#1. A significant problem in learning physics is being able to memorize all the information I need to know.	66.7% agree	9.1% agree
#4. It is useful for me to do lots and lots of problems when learning physics.	74% strongly agree	16% strongly agree
#9. I find that reading the text in detail is a good way for me to learn physics.	7.4 % disagree	41.7 % disagree
#10. There is usually only one correct approach to solving a physics problem.	12% strongly disagree	42% strongly disagree
#29. To learn physics, I only need to memorize solutions to sample problems.	45.5% strongly disagree	58.3% strongly disagree

These results seem to support the notion that students have now recognized that physics requires more than just a memorized and rote approach to problem solving. In order to helping them achieve success in physics and reach those higher mental activity processes mandated by the program of studies other means or strategies must be used in order to best apply the physics principles to novel problems.

A reflective journal was kept for the length of the study in order to record teacher observations during student completion of each of the simulation activities. This journal also kept a time schedule of the unit length of the intervention class to compare with the control group. In the initial planning of the study and lessons it was determined that the unit length would be longer by approximately five class periods. It was noted however that the unit length was only longer by three periods and not a significant change from the control group thus not affecting the completion of the pother program outcomes of the course. The journal was also used to monitor and record student behavior during the

completion of the activities. Of the six activities only one chosen simulation, the vector addition simulation was met with some resistance by the students. This was due to the inability to change the magnitude of the vectors easily and as a result the students became very frustrated and quickly dismissed the merit of using the simulation. All the other activities had the students actively engaged in the task at hand, they worked collaboratively on the activities were motivated to get their work done. One of the main benefits of the simulations was that if the activities were not completed during class time the students were able to finish outside of class as opposed to a lab scenario where sometimes they can “feel rushed and as a result affect their understanding.”

INTERPRETATION AND CONCLUSION

Computer simulations promote student learning by providing a visual aid that supports conceptual understanding, increases student achievement and engages the learner. As Blake and Scanlon (2007) stated “simulations do not work on their own, there needs to be some structuring of the students’ interactions with the simulation to increase effectiveness” (p. 492). This AR project found that when traditional instruction was supplemented with computer simulations students were able to successfully engage the material at a higher cognitive level. The simulations kept the students motivated and engaged during class time, provided that the simulation activity was deemed worthwhile and the simulation itself was well organized and easy to use. The teacher created inquiry activities that accompanied the simulations needed to be well constructed and have clearly defined learner goals for students to benefit from them.

Some of the noted drawbacks of supplementing instruction with simulations were that all simulations are not created equal. There is a wide range of diversity amongst simulations found on the internet each demonstrating their own unique features, strengths and weaknesses. It was noted by over half of the intervention group that the vector addition simulation was “not very helpful” since it had limitations on the size of the vectors that could be created and users were unable to input specific values for the vectors.

Another downside to some of the simulations is that they were unhelpful in explaining the mathematics behind most of the applicable physics concepts, in other words they would just display the numerical values for the user. As a result, it did help students visualize and make connections to the relationships studied in the simulation but teacher instruction was needed to explain the mathematical process behind the principles shown in the simulations. Although stated as a negative design drawback, this did however promote and foster excellent class discussion and pushed students higher up Bloom’s taxonomical levels. It seemed to engage their inquiry efforts as they wanted to know what caused these values to change.

The simulations chosen were from three different sources and as a result had three very different interfaces for the students to navigate. The PhET simulations, Vector Addition and Gravitational Force Lab, provided very little guidance for the students and were designed with a true inquiry nature in mind. The student activities did provide minimal guidance with the attempt to encourage concept exploration by the students and the majority of the students handled these tasks with minimal help while others struggled. As one student commented, “if there was a guide next to the simulation to help us out

when we were stuck it would have been beneficial.” As stated earlier the vector addition simulation were not favoured by the students due to the fact that the vectors had a limit to their size and the user had difficulty manipulating the vector size making it difficult to complete addition problems. The Gravitational Force Lab simulation however was better received by the students as they did not encounter the frustration in manipulating the parameters as in the vector simulation.

The second type of simulation used was designed by ExploreLearning and of the three types the most visually appealing and seemed to be the most developed. The Atwood Machine simulation was navigated with ease by the students and the concepts explored were very in depth and challenging. There were numerous options, resources and guides to assist the students and they “enjoyed the ease of use” of this simulation. What set it apart was that it displayed concepts graphically and numerically and the students appreciated both these displays.

The third type of simulation available through Alberta Learning were the most dated and simplistic of the three but was still very effective in assisting the students with meeting the learner outcomes. Although simplistic in design they were easy to collect data and students easily saw the cause and effect changes from their manipulations. It made their experiences with these simulations useful and constructive in nature.

Based on this study it can be concluded that computer simulations are extremely valuable learning tools, if not necessary, to improve student learning and conceptual understanding. They have demonstrated that they improve student achievement and have a positive influence on student attitudes regarding problem solving. However in order to effectively achieve these objectives consistently a complete integration of the simulations

throughout instructional practices is needed. Examples of how this may occur, include students completing inquiry activities regularly, students completing pre-lab assignments using simulations prior to a traditional lab or the replacement of traditional labs for simulations and finally they may be embedded throughout lecture based instruction in the form of an interactive lecture.

VALUE

This action research project had a profound impact on me and my classroom. It has introduced me to a 21st century learning environment that is highly effective in motivating, engaging and challenging students in a unique and very accessible way. Lesson plans now begin with locating simulations that have the potential to assist my instruction and supplement my lessons. I have continued their use in all my classes and have modelled this amongst my colleagues by presenting my findings at a district professional development day to a large number of science teachers. I discussed the benefits and suggested ways to implement the use of simulations in their classroom encouraged them to explore their use further and have received positive feedback from many colleagues.

This project has also reinforced the need to provide meaningful instruction through differentiation of teaching methods. Although a large majority of students valued the simulations there were a small minority that would prefer “being taught by the teacher” and were more comfortable using their “pencil and paper” to do physics. It should be noted however that all students agreed that the simulations provided a necessary visualization of the concepts which is extremely useful for an abstract subject

such as physics. As an experienced teacher I sometimes forget the difficulties my students may face and assume these students can create the necessary visuals without any assistance. It has forced me to be a more reflective teacher and cognizant of my methods of how I present the material.

While computer simulations have a positive effect on conceptual understanding, the research reveals many unanswered questions and potential additional studies. This study focused just on the use of the simulations without regard to the attributes that make a simulation beneficial to student learning and whether or not there any pitfalls or drawbacks to using computer simulations. It also did not look at the specific design parameters of the simulations and evaluate effectiveness of these particulars. Perhaps the most significant and useful study would be to see what the most effective ways of implementing computer simulations in the classroom are to improve student learning.

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APPENDICES

APPENDIX A

COMPARISON REVIEW EXAM

APPENDIX A: COMPARISON REVIEW EXAM

**PHYSICS 20
Review Exam****NAME:**

1. State the number of significant digits in each of the following.

- /4
- | | |
|----------------|------------------|
| a) 0.006 _____ | c) 217.000 _____ |
| b) 2700 _____ | d) 1.00001 _____ |

2. Write the following in opposite (standard or positional) notation.

- /4
- | | |
|------------------|--|
| a) 0.00075 _____ | c) 8.1×10^{-3} _____ |
| b) 36 000 _____ | d) 250×10^4 (give S.N.) _____ |

3. Calculate; round answers correctly. Unless otherwise stated, assume all numbers are measurements.

- /5
- | | |
|---|--|
| a) $\begin{array}{r} 147.5 \text{ cm} \\ + 21.98 \text{ m} \\ + 567 \text{ cm} \end{array}$ _____ | c) 120 candies divided among
20 students _____ |
| b) $14.5 + 10.2 - 2.4$ _____ | d) $(2.45 \times 10^{-2}) \div (4 \times 10^{-1})$ _____ |
| e) $(12)(0.65)(18.2)$ _____ | |

4. Solve for the indicated variables; show work and round answers correctly.

a) $C = \frac{5}{9}(F - 32)$

$C = 150^\circ \quad F = ?$

/6

b) $a = \frac{v_f - v_i}{t}$
 $a = -6.0 \quad v_f = 9.00$

$v_i = ? \quad t = 3.5$

5. Convert each of the following.

a) 23 L = _____ cL e) 21 000 days = _____ s

b) 120 dam = _____ mm f) 4 700 W = _____ kW

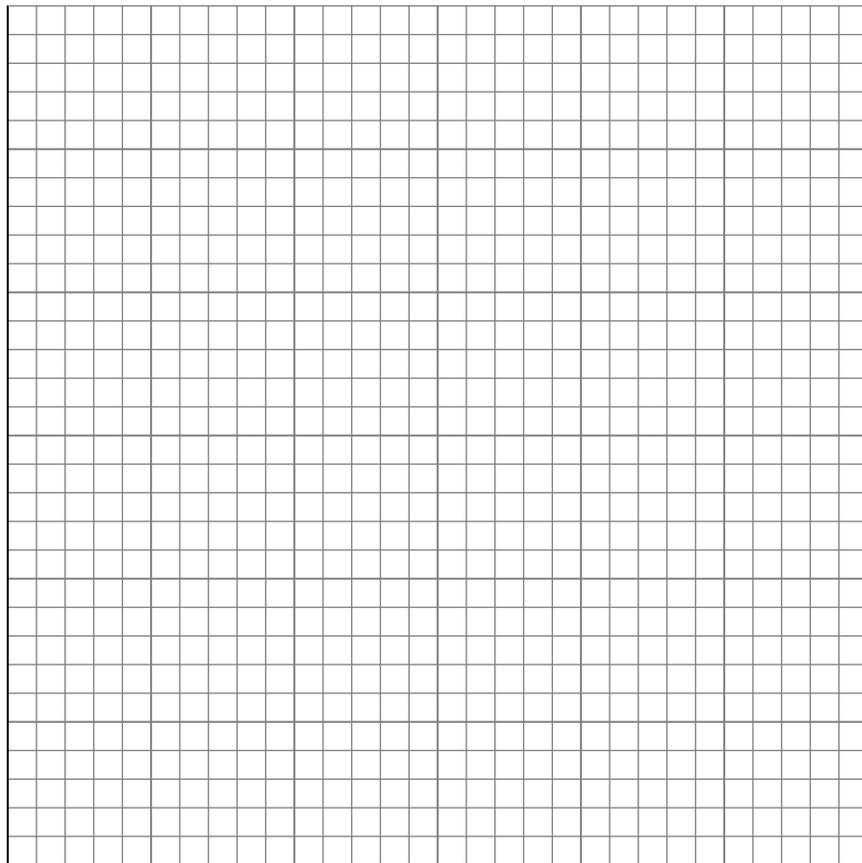
c) 125 a (years) = _____ h g) 245 000 N = _____ mN

d) 1.2 Mm = _____ dm h) 6×10^6 g = _____ Mg

6. Students performing a lab in physics measure the distance covered by a battery-powered toy car as it accelerates across a table top. The chart below shows distance covered against time.

d (cm)	0	3.2	13	29	51	77	103	128
t (s)	0	2	4	6	8	10	12	14

a) Plot a graph of the data on the grid below.



/5

/5 b) Analyze the graph to find the car's velocity at $t = 4$ s. Describe the relationship shown in the graph and show any needed constructions on the graph.

APPENDIX B

CLASS SURVEY

APPENDIX B: CLASS SURVEY

Introduction

Here are a number of statements that may or may not describe your beliefs about learning physics. You are asked to rate each statement by circling a number between 1 and 5 where the numbers mean the following:

1. Strongly Disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly Agree

Choose one of the above five choices that best expresses your feeling about the statement. If you don't understand a statement, leave it blank. If you understand, but have no strong opinion, choose 3.

Survey

1. A significant problem in learning physics is being able to memorize all the information I need to know.

Strongly Disagree 1 2 3 4 5 Strongly Agree

2. When I am solving a physics problem, I try to decide what would be a reasonable value for the answer.

Strongly Disagree 1 2 3 4 5 Strongly Agree

3. I think about the physics I experience in everyday life.

Strongly Disagree 1 2 3 4 5 Strongly Agree

4. It is useful for me to do lots and lots of problems when learning physics.

Strongly Disagree 1 2 3 4 5 Strongly Agree

5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.

Strongly Disagree 1 2 3 4 5 Strongly Agree

6. Knowledge in physics consists of many disconnected topics.

Strongly Disagree 1 2 3 4 5 Strongly Agree

7. As physicists learn more, most physics ideas we use today are likely to be proven wrong.

Strongly Disagree 1 2 3 4 5 Strongly Agree

8. When I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values.

Strongly Disagree 1 2 3 4 5 Strongly Agree

9. I find that reading the text in detail is a good way for me to learn physics.

Strongly Disagree 1 2 3 4 5 Strongly Agree

10. There is usually only one correct approach to solving a physics problem.

Strongly Disagree 1 2 3 4 5 Strongly Agree

11. I am not satisfied until I understand why something works the way it does.

Strongly Disagree 1 2 3 4 5 Strongly Agree

12. I cannot learn physics if the teacher does not explain things well in class.

Strongly Disagree 1 2 3 4 5 Strongly Agree

13. I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.

Strongly Disagree 1 2 3 4 5 Strongly Agree

14. I study physics to learn knowledge that will be useful in my life outside of school.

Strongly Disagree 1 2 3 4 5 Strongly Agree

15. If I get stuck on a physics problem my first try, I usually try to figure out a different way that works.

Strongly Disagree 1 2 3 4 5 Strongly Agree

16. Nearly everyone is capable of understanding physics if they work at it.

Strongly Disagree 1 2 3 4 5 Strongly Agree

17. Understanding physics basically means being able to recall something you've read or been shown.

Strongly Disagree 1 2 3 4 5 Strongly Agree

18. There could be two different correct values to a physics problem if I use two different approaches.

Strongly Disagree 1 2 3 4 5 Strongly Agree

19. To understand physics I discuss it with friends and other students.

Strongly Disagree 1 2 3 4 5 Strongly Agree

20. I do not spend more than five minutes stuck on a physics problem before giving up or seeking help from someone else.

Strongly Disagree 1 2 3 4 5 Strongly Agree

21. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.

Strongly Disagree 1 2 3 4 5 Strongly Agree

22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations.

Strongly Disagree 1 2 3 4 5 Strongly Agree

23. In doing a physics problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem.

Strongly Disagree 1 2 3 4 5 Strongly Agree

24. In physics, it is important for me to make sense out of formulas before I can use them correctly.

Strongly Disagree 1 2 3 4 5 Strongly Agree

25. I enjoy solving physics problems.

Strongly Disagree 1 2 3 4 5 Strongly Agree

26. In physics, mathematical formulas express meaningful relationships among measurable quantities.

Strongly Disagree 1 2 3 4 5 Strongly Agree

27. It is important for the government to approve new scientific ideas before they can be widely accepted.

Strongly Disagree 1 2 3 4 5 Strongly Agree

28. Learning physics changes my ideas about how the world works.

Strongly Disagree 1 2 3 4 5 Strongly Agree

29. To learn physics, I only need to memorize solutions to sample problems.

Strongly Disagree 1 2 3 4 5 Strongly Agree

30. Reasoning skills used to understand physics can be helpful to me in my everyday life.

Strongly Disagree 1 2 3 4 5 Strongly Agree

31. We use this statement to discard the survey of people who are not reading the questions. Please select agree-option 4 (not strongly agree) for this question to preserve your answers.

Strongly Disagree 1 2 3 4 5 Strongly Agree

32. Spending a lot of time understanding where formulas come from is a waste of time.

Strongly Disagree 1 2 3 4 5 Strongly Agree

33. I find carefully analyzing only a few problems in detail is a good way for me to learn physics.

Strongly Disagree 1 2 3 4 5 Strongly Agree

34. I can usually figure out a way to solve physics problems.

Strongly Disagree 1 2 3 4 5 Strongly Agree

35. The subject of physics has little relation to what I experience in the real world.

Strongly Disagree 1 2 3 4 5 Strongly Agree

36. There are times I solve a physics problem more than one way to help my understanding.

Strongly Disagree 1 2 3 4 5 Strongly Agree

37. To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.

Strongly Disagree 1 2 3 4 5 Strongly Agree

38. It is possible to explain physics ideas without mathematical formulas.

Strongly Disagree 1 2 3 4 5 Strongly Agree

39. When I solve a physics problem, I explicitly think about which physics ideas apply to the problem.

Strongly Disagree 1 2 3 4 5 Strongly Agree

40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own.

Strongly Disagree 1 2 3 4 5 Strongly Agree

41. It is possible for physicists to carefully perform the same experiment and get two very different results that are both correct.

Strongly Disagree 1 2 3 4 5 Strongly Agree

42. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.

Strongly Disagree 1 2 3 4 5 Strongly Agree

APPENDIX C

VECTOR ADDITION ACTIVITY

APPENDIX C: VECTOR ADDITION ACTIVITY

USING THE PhET SIMULATION: VECTOR ADDITION

Student Learning Outcomes

20-A1.4s –use appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate ideas, plans and results

20-B1.6k – calculate the resultant force, or its constituents, acting on an object by adding vector components graphically and algebraically

20-B1.3s – use free-body diagrams to describe the forces acting on an object

Student Instructions

1. Go to the following website:

http://phet.colorado.edu/sims/vector-addition/vector-addition_en.html

2. Click “Run Now!” to get the simulation loaded.

3. Take 5 minutes to explore the simulation to get comfortable and familiar with the controls.

4. In the simulation, a vector is described by four measurements: $|R|$, Θ , R_x , and R_y . This R (vector) can represent velocity, displacement and/or force. Put a vector in the work area, and then **analyze** what these four things represent. **Describe** in your own words what the measurements represent and what “component” means.

5. Using the simulation **determine** the vertical and horizontal components of each vector; include a sketch:

a) 4.0N @ 45°

b) 2.60 kN @ 195°

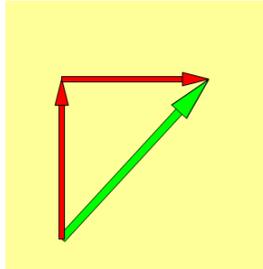
c) 8.0 N @ 290°

d) 5.6 N @ 180°

6. Now you are going to learn how to add vector quantities in physics. A vector can be represented graphically by an arrow of a certain length and direction, just like a vector quantity has a magnitude and direction (usually expressed in degrees). Vectors can be added together, graphically and algebraically to produce a vector sum or resultant. The resulting diagram is known as a vector addition diagram. To have the simulation assist you in this endeavour grab an arrow from the bucket. The length of the vector is found in

the |R| box. The angle of the vector is in the θ box. Place the vectors you wish to add head to tail. To get the resultant vector, hit the big “SUM” button. Move the green sum vector so that the tail touches the tail of your first vector.

Example of two dimensional vector diagram (note labels are missing a proper vector addition diagram includes labels for each arrow and the angle is also stated):



7. Use the simulation to help you **determine** the net force acting on the objects in the following situations. As part of your response to each question include a **sketch** of the vectors, include a free-body diagram and labeled vector addition diagram and **determine** the resultant, including direction, using the simulation and algebraically.

- a) force of 14 N, north and 13 N, north is applied to an object at rest.
- b) force of 13.7 N, down and 12.0 N, up and 10.5 N, down is applied to a resting object.
- c) A car is stuck in a snow drift. Bob and Jane attach two ropes to the vehicle and try to pull it out by pulling in the same direction. Bob pulls with a force of 17N while Jane pulls with a force of 12 N. If there is a force of friction of 4.0 N acting on the car determine the net force.
- d) In a tractor pull, four tractors are connected by strong chains to a heavy load. The load is initially at rest. Tractors A and B pull with forces of 15.0 kN [E] and 14.0 kN [E] respectively. Tractors C and D pull with forces of 14.5 kN [W] and 13.5 kN [W] respectively. The magnitude of the force of friction exerted by the ground on the load is 10.0 kN.
- e) If two forces act on an object, state the angle between these forces that will result in the net force given below. Explain using sketches.
 - (i) maximum net force
 - (ii) minimum net force
- f) A force of 17.0 N, north and a force of 14.0 N, east act on a box.
- g) A force of 21 N south and a force of 23 N east act on an object.
- h) The total weight of a biker and her motorbike is 1800 N [down]. With the engine engaged, the force of friction exerted by the road on the tires is 500 N [forward]. The air

resistance acting on the biker and bike is 200 N [backward]. The normal force exerted by the road on the biker and bike is 1800 N [up].

- i) A force of 13.5 N, 180° and a force of 22.0 N, 90° act on an object.
- j) Explain in your own words how you draw a vector addition diagram.

APPENDIX D

FLETCHER'S TROLLEY ACTIVITY

APPENDIX D: FLETCHER'S TROLLEY ACTIVITY

*Physics 20: Exploring Acceleration, Net Force and Mass Relationships***Part 1: Acceleration Observed**

Imagine two blocks connected by a rope. Now, imagine that one of the blocks is hung over the edge of a table via a pulley. What would happen to the blocks if they were free to move? Would both blocks begin to accelerate, and if so would they accelerate at the same rate if the rope does not stretch? The apparatus used to answer such questions is known as Fletcher's Trolley. We will investigate these questions using a simulated Fletcher's Trolley.

The applet will be used to observe the acceleration of two blocks on Fletcher's Trolley.

- Click "Reset" (↺). The lower edge of block 2 will then be at elevation $h = 1.30$ m, and the yellow platform at $h = 0$ m, as in Figure 1.

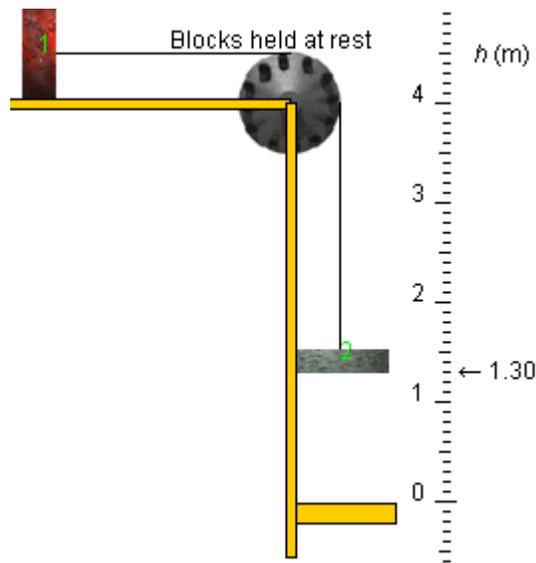


Figure 1

The masses of the blocks will be:

$$m_1 = 600 \text{ g (this cannot be changed)}$$

$$m_2 = 400 \text{ g}$$

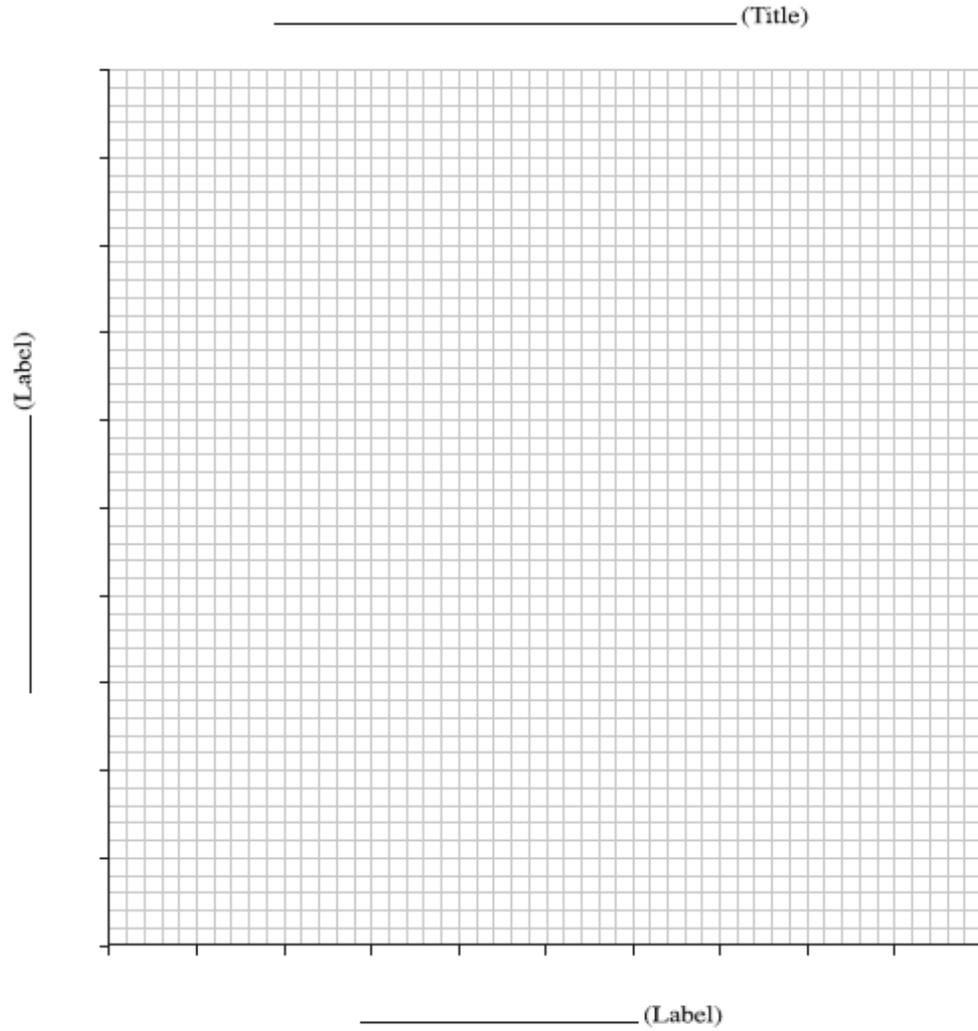
The pulley's mass will be zero. These mass values will be assumed in all of the following explanations, except where otherwise noted.

- b. Click on block 1 and drag it until block 2 is at elevation $h = 3.00$ m. Maximize (☐) the applet window if you are not able to drag block 1 far enough to the left.
- c. Click "Play" (▶) and observe the motion of the blocks. Describe the motion of the blocks using the terms speed, time, and acceleration.

The acceleration of the blocks can be determined by calculating the slope of a velocity vs. time graph. Click "Replay" (◀◀) and click "Step Forward" (▶) to move slowly through the motion. Record the velocity at each of the following times in the table below.

- a. The time and velocity data is found on the left side of the applet display panel. Using this data, construct a velocity vs. time graph.

time (t) s	velocity (v) m/s
0.00	0.0
0.04	
0.08	
0.12	
0.16	
0.20	
0.24	
0.28	
0.32	
0.36	



- b. Using graphical analysis, **determine** the acceleration of the trolley. **Relate** the slope to a physics equation algebraically (remember the definition of acceleration from Science 10).

- c. The constant slope indicates that the acceleration is constant. **Compare** your value with that shown by the applet ($a = 3.92 \text{ m/s}^2$).
- d. **Explain** why would one expect the accelerations of the blocks in Fletcher's Trolley to be constant?

Part 2: How is the acceleration of an object related to the net force acting on the object?

Hypothesis

State a hypothesis relating acceleration and net force using an if/then statement.

Variables

Identify the controlled, manipulated and responding variables for your procedure.

Materials

Fletcher's Trolley Simulation

Procedure

With a partner design a procedure that allows you to identify the relationship between net force and acceleration. Remember in a lab multiple trials are needed to ensure accuracy and a graph of the results is expected in order to visually represent the relationship.

APPENDIX E

ATWOOD MACHINE ACTIVITY

APPENDIX E: ATWOOD MACHINE ACTIVITY

This activity can be accessed from the following website:

<http://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=>

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APPENDIX F

INCLINED PLANE, FRICTIONLESS ACTIVITY

APPENDIX F: INCLINED PLANE, FRICTIONLESS ACTIVITY

Physics 20: Inclined Plane, Frictionless Simulation

Inclined Plane, Frictionless simulates the motion and forces acting on a mass moving down a smooth, frictionless incline.

Prerequisites

Students should be familiar with the concepts of weight and normal force. Students should also have a working knowledge of free body diagrams and vector component analysis.

Learning Outcomes

- Students will be able to construct a free body diagram and determine the net force acting on an object resting on an incline plane.
- Students will be able to calculate the normal force, weight, and weight components acting on an object on a frictionless incline.

Instructions

Students should understand the applet functions that are described in Help and ShowMe. The applet should be open. The step-by-step instructions on this page are to be done in the applet. You may need to toggle back and forth between instructions and applet if your screen space is limited.

1. Free Body Diagram and Analysis

Free body analysis can be used to determine the observed or net acceleration of an object that has multiple forces acting on it. For example, consider the case of a box of crayons resting on a frictionless incline, which is 30° to the horizontal. The box of crayons will accelerate down the incline at a rate that is determined by the forces acting on it. The applet will be used to show these forces.

Exercise 1

On the applet, click the "Show FBD" check box (Show FBD) and the "Show FBD

Components" check box (Show FBD Components) to display all of the forces. You

can clearly see **two** forces acting on the box:

- gravitational force acting straight down
- normal force acting at right angles to the plane of the incline

Sketch and label these two forces on Figure 1 to the right.

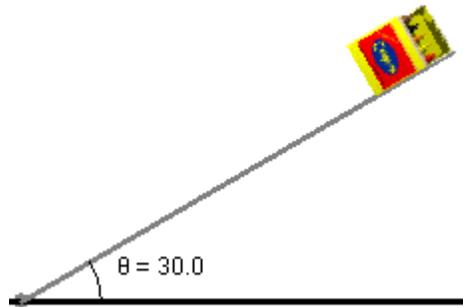


Figure 1

Exercise 2

On the applet, click the "Show FBD" check box (Show FBD) and the "Show FBD Components" check box (Show FBD Components) to display all of the forces. Try to reproduce a FBD similar to Figure 2. Define the following vectors:

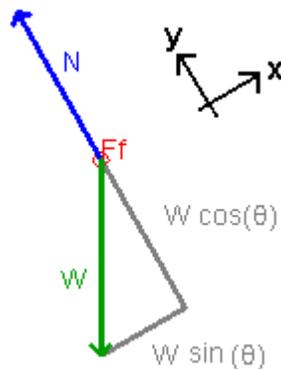


Figure 2

- a. Normal force (N):

b. Weight (W):

Note that **F_f** indicates the force of friction is zero in this example. Also note that the weight force has been resolved into two components: one component is opposite the normal force while the other is parallel to the incline. Assume that the "x-direction" is parallel to the incline and that the "y-direction" is perpendicular to the incline.

Exercise 3

In this diagram, one of the forces is "balanced" by a component of the other. Identify these forces.

_____ = _____

Exercise 4

In the configuration shown to the right, will the normal and weight forces add to give a net force of zero? If not, which force (or component of force) is not balanced by another force?

Exercise 5

Detailed information about the forces is found in the upper right corner of the drawing panel. From the FBD we conclude that there is:

- a component of the weight that acts perpendicular to the incline, given by the expression $W_y = (W)(\cos\theta)$
- a component of the weight that acts parallel to the incline, given by the expression $W_x = (W)(\sin\theta)$

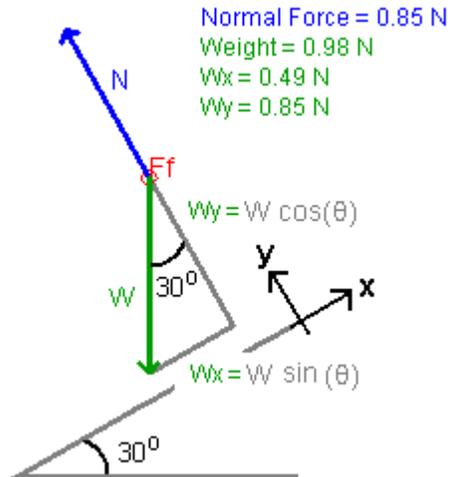


Figure 3

Verify that the magnitude of the components, as given by the applet, are correct.

$W_y =$

$W_x =$

2. The Normal Force

The incline must exert a force on the box of crayons; otherwise, it would "fall through" the surface. This force is the normal force, and it is always directed perpendicular to the surface. Based on Figure 3, the normal force is equal in magnitude to the component of the object's weight that is perpendicular to the surface of the incline (W_y). The applet will be used to investigate how the magnitude of the normal force changes as the angle of the incline is varied.

Exercise 6

Set the applet up similar to the Figure 4.

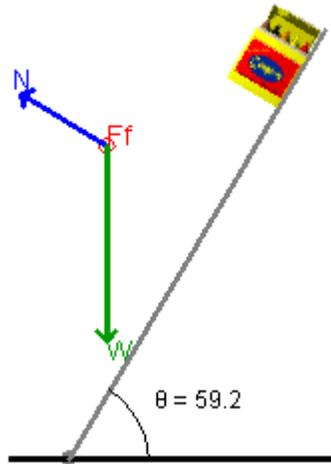


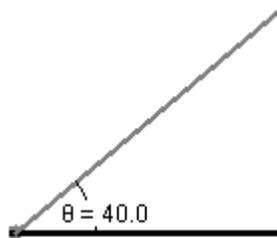
Figure 4

- As the angle of inclination increases, the magnitude of the normal force _____.
- At any angle of incline the magnitude of the normal force is always equal to _____.

3. Questions and Problems

Exercise 7

On the incline below, draw a free body diagram for a block on an incline at a 40° angle. Carefully label the incline angle, normal force, weight, component of weight perpendicular to the surface and the component of the weight acting parallel to the surface.



Exercise 8

APPENDIX G

FRICION ACTIVITY

APPENDIX G: FRICTION ACTIVITY

Friction Simulation – Physics 20

Friction simulates the force exerted on a spring (force) scale as it pulls a stack of books across a rough table surface in order to explore the difference between kinetic and static friction.

Prerequisites

Students will require a working knowledge of normal force, weight, free body diagrams, and graphical analysis.

Learning Outcomes

Students will be able to graphically determine an expression for kinetic friction and calculate kinetic, static and rolling friction in a variety of situations. Students will also be able to qualitatively and quantitatively compare kinetic, static, and rolling friction.

Instructions

Students should understand the applet functions that are described in Help and ShowMe. The applet should be open. The step-by-step instructions on this page are to be done in the applet. You may need to toggle back and forth between instructions and applet if your screen space is limited.

Contents

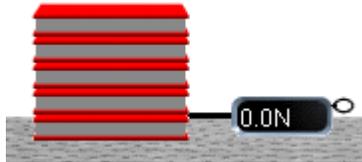
1. [Comparing Kinetic and Static Friction](#)
2. [Developing an Expression for Kinetic Friction](#)
3. [Summarizing the Force of Friction](#)
4. [Calculating Frictional Force - Examples](#)
5. [Problem Solving](#)

1. Comparing Kinetic and Static Friction

The applet will be used to demonstrate the difference between Kinetic and Static Friction.

Exercise 1

On the applet, stack the five books that are attached to the force scale as shown below.



a. Using the mouse, slowly pull on the open ring of the force scale and observe the reading on the scale just as the stack of books begins to move.

What is the maximum force applied before the books start to move? _____ N

b. Once the books begin to move, the force required to keep the books moving is reduced.

What is the applied force required to keep the books moving? _____ N

Exercise 2

Before the stack of books begins to move, the force of friction is called **Static Friction**. After the motion begins, the stack of books is subject to **Kinetic Friction**. *In your own words, describe the relationship between the size of the Static Frictional Force and the Kinetic Frictional Force.*

Exercise 3

Click "FBD" (👤) to display the FBD drawing. In Figure 1, the red vector represents the **frictional force (F_f)** while the brown vector represents the **applied force (F)**. *Describe the behavior of the FBD as you pull on the force scale.*

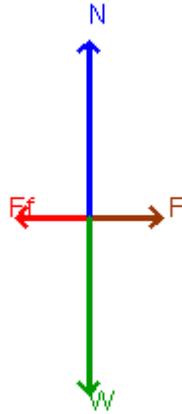


Figure 1

- What happens to the size of the static frictional force as you start to pull on the force scale?
- Is there a maximum size for the static frictional force? If so, what happens to the object if the applied force exceeds the maximum static frictional force?
- Is there a minimum size for the static frictional force? If so, under what conditions will the minimum static frictional force be observed?
- What type of frictional force acts when the system is at rest?

2. Developing an Expression for Kinetic Friction

The force of friction arises from an interaction between surfaces. In the case of the books and rough table surface, the table surface exerts a force on the bottom book. This force is the **normal force (F_N)** and is represented in blue on Figure 1. Opposing the normal force is the object's weight. The **weight (W)** is represented in green on Figure 1. For the books resting on the table, the normal force is equal in magnitude to the weight. The normal force and weight are "balanced". The magnitude of the normal force can be calculated by equating it to the weight. For example,

$$F_N = W$$

$$F_N = mg$$

Exercise 4

Even though friction is an extremely complex phenomenon, there is a very simple relationship between the magnitude of the frictional force and the normal force.

a. Using the applet, measure the applied force required to keep the books moving and complete the following table. To calculate the normal force, assume that each book has a mass of 1.00 kg.

Number of Books	Normal Force (N) $F_N = mg$	Kinetic Frictional Force (N)
1	_____	_____
2	_____	_____
3	_____	_____
4	_____	_____
5	_____	_____
6	_____	_____
7	_____	_____
8	_____	_____
9	_____	_____
10	_____	_____

b. Using graphical analysis, **determine** the coefficient of kinetic friction (μ) for the book - table interface. As part of your response, **complete** the data table above, **provide** a graph of the responding variable as a function of manipulated variable, **determine** the slope of your graph, and **relate** the slope algebraically to a physics equation. **State** all necessary physics concepts and formulas.

3. Summarizing the Force of Friction

Frictional forces are complicated. They depend not only on the two objects involved but also their conditioning at the moment of the interaction of the two objects. For example, roads made of asphalt become very slippery when freezing rain or snow covers the

surface and tires lose their grip when they are worn. Furthermore, even if all these circumstances are fixed, the frictional force also depends on whether an object rolls, slides (kinetic), or is stationary (static) with respect to the other surface.

This gives rise to three basic forms of friction:

Kinetic Friction

When an object slides, it experiences a frictional force.

$$F_{kinetic} = \mu_k F_N$$

Kinetic frictional force always opposes motion. It acts opposite the direction of motion.

Static Friction

When an object is at rest a static frictional force resists motion.

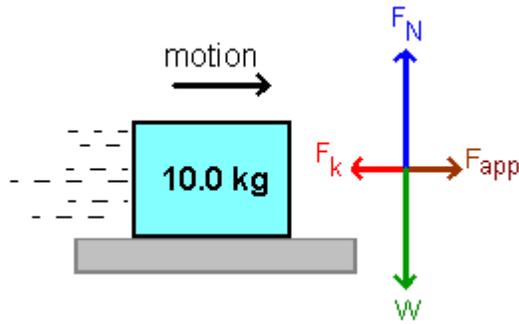
$$F_{static} \leq \mu_s F_N$$

The maximum static frictional forces are larger than the kinetic frictional forces.

μ_k and μ_s are the coefficient of rolling, kinetic, and static friction and F_N is the normal force.

4. Calculating Frictional Force - Examples

1. The coefficient of kinetic friction between a block and the level surface it slides on is 0.45. If the mass of the block is 10.0 kg, what is the minimum force needed to keep the block moving with uniform motion?



$$F_k = \mu_k F_N$$

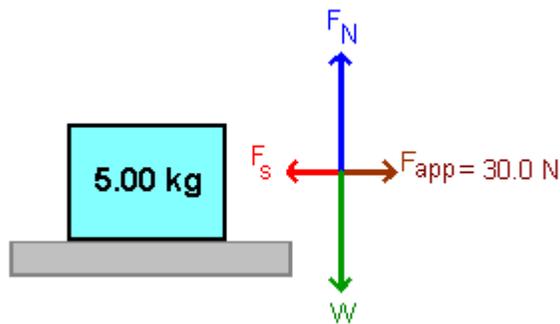
$$F_k = \mu_k (mg)$$

$$F_k = (0.45)(10.0 \text{ kg})(9.81 \text{ m/s}^2)$$

$$F_k = 44 \text{ N}$$

The applied force need only balance the kinetic frictional force in order to maintain uniform motion.

2. A student pulls on a 5.00 kg object and discovers that she needs to exert 30.0 N of force before the object moves. What is the coefficient of static friction between the object and the surface on which it rests?



Since the applied force is 30.0 N **just** before moving, the frictional force must be equal in size. Therefore,

$$F_s \leq \mu_s F_N$$

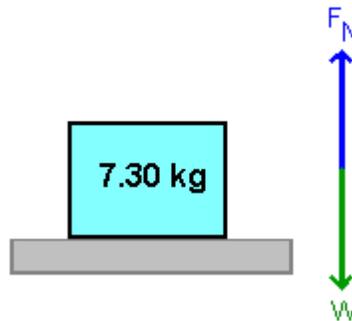
$$\mu_s \geq \frac{F_s}{F_N}$$

$$\mu_s \geq \frac{F_s}{(mg)}$$

$$\mu_s \geq \frac{30.0 \text{ N}}{(5.00 \text{ kg})(9.81 \text{ m/s}^2)}$$

$$\mu_s \geq 0.612$$

3. A 7.30 kg box is at rest on a level table. The coefficient of static friction between the box and table is 1.03. How big is the static frictional force?

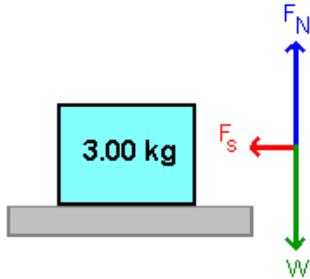


There is no static frictional force acting since there is no net force attempting to move the box. The static frictional force could, at most, be equal to $\mu_{static} F_N$.

5. Problem Solving

Exercise 8

A student drew the free body diagram for a box sitting at rest on the floor. **Explain** what is wrong with this diagram.



Exercise 9

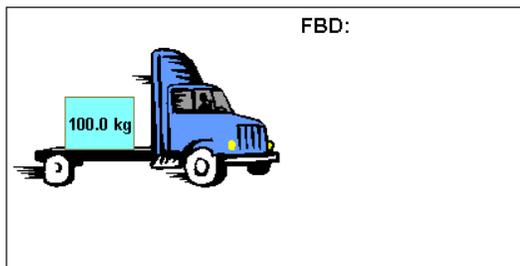
The coefficient of static friction between a book and the level surface it slides on is 0.65. If the mass of the book is 2.0 kg, **determine** the minimum applied force required to move the books?

Exercise 10

An engine provides 300.0 N of force to keep a 1600 kg vehicle moving at a uniform speed (air resistance is negligible). What is the coefficient of rolling friction between the tires and the road surface?

Exercise 11

A 100.0 kg crate is at rest in the back of a truck. If the coefficient of static friction between the crate and the truck bed is 0.30, what is the maximum acceleration that the truck can have before the crate begins to slide? **Draw** a Free Body Diagram and **explain** what force causes the crate to accelerate along with the truck.



Exercise 12

Anti-lock brakes prevent car tires from locking up and skidding. **Explain** why a car can stop faster and safer if the tires do not skid.

APPENDIX H

GRAVITY FORCE LAB ACTIVITY

APPENDIX H: GRAVITY FORCE LAB ACTIVITY

Student objectives:

- Design 2 experiments that allow you to derive an equation that relates mass, distance, and gravitational force.
- Use graphical analysis to determine the universal gravitational constant.

Your report must include the following parts:

- Purpose
- Hypothesis
- Procedure
- Observations
- Analysis – must include a graph for each experiment and your graphical analysis must relate the slope to the equation
- Evaluation

APPENDIX I

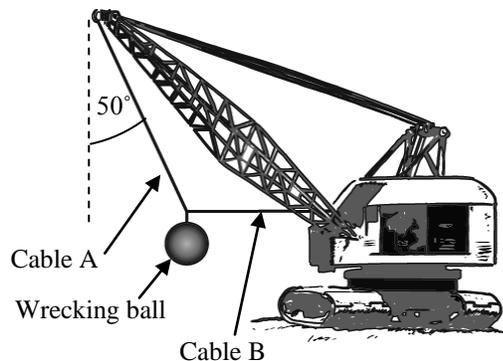
VECTOR QUIZ

APPENDIX I: VECTOR QUIZ

Physics 20 – Vector Addition/Equilibrium Quiz

Name: _____

1. **Describe** the difference between a scalar and vector quantity, provide an example of each. (4)
2. **Explain** how you draw a vector diagram. (3)
3. **Determine** the resultant for each vector sum, including magnitude and direction using a standard position angle (Cartesian system). As part of your response **draw** a free-body diagram, **sketch** a vector addition diagram and **state** all necessary physics principles and formulas.
 - a) a force of 5.0 N, north and a force of 8.0 N, south act on an object. (10)
 - b) $F_1=32.0\text{ N}$ at 38.0° and $F_2=16.0\text{ N}$ at 340° (10)
4. The diagram below shows a crane equipped with a wrecking ball of weight 9000N. The ball is suspended from cable A and pulled away from the vertical by a horizontal cable B to the position shown. If the ball is in equilibrium **determine** the tension in each cable. As part of your response **draw** a free-body diagram, **sketch** a vector addition diagram and **state** all the necessary physics principles and formulas. (8)



APPENDIX J

NEWTON'S LAWS QUIZ

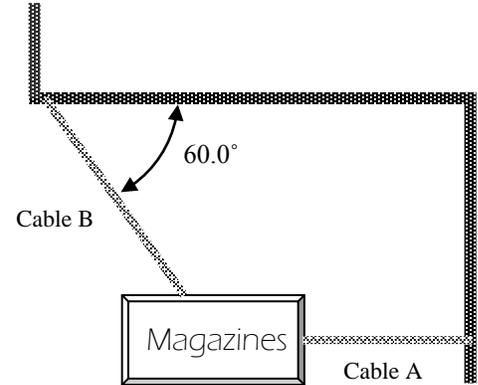
APPENDIX J: NEWTON'S LAWS QUIZ

PHYSICS 20: Newton's Law Quiz

NAME:

1. A sign with a weight of 250 N is suspended from two supporting cables A and B as shown.

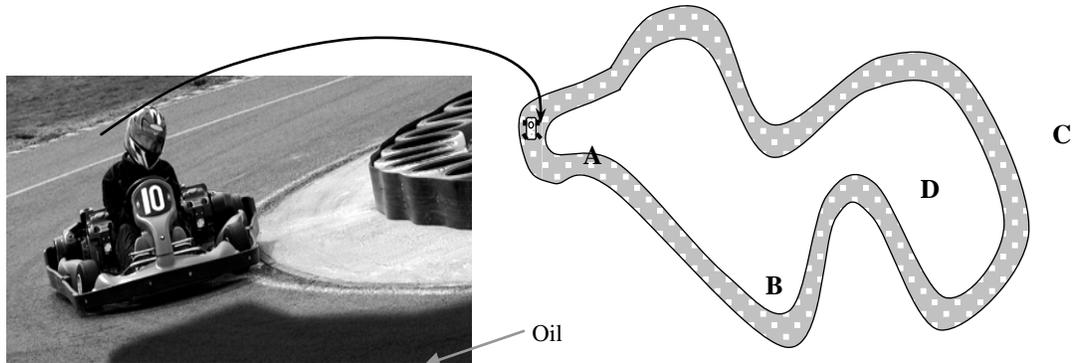
Determine the tension force in each cable. As part of your response **sketch** a labeled free body diagram and **state** all necessary physics concepts, formulas and substitutions. (9 marks)



2. A student inflates a balloon, and then releases the neck with the balloon parallel to the ground. The balloon, which has an initial mass (including air) of 0.0550 kg, moves forward horizontally with an initial acceleration of 7.50 m/s^2 . The force of air resistance acting against the balloon's motion initially equals 0.400 N.
- **Explain**, using one of Newton's laws of motion, why the balloon moves. Be sure to **state** the law you used.
 - **Determine** the net force that moves the balloon forward.
 - **Determine** the force exerted by the escaping air on the balloon – the applied force.

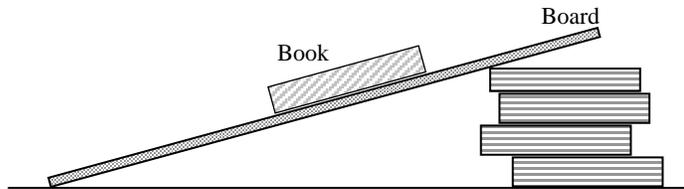
As part of your response **sketch** a labeled free body diagram and **state** all necessary physics concepts, formulas and substitutions. (10 marks)

3. The go-carter shown below left is just rounding a sharp left-hand turn on a horizontal track. His position (point A) is sketched on the track diagram below right.



- Just ahead of the go-cart is a patch of oil on the track. On the track **sketch** an arrow to show the likely direction taken by the go-cart as friction between the cart's tires and the track drops effectively to zero due to the oil. (1 mark)
 - Use one or more of Newton's laws to **explain** what happens in part (a). **State** the law you used in your response. (3 marks)
 - On the previous (oil-free) lap, the go-cart accelerated along the straightaway at B at 6.50 m/s^2 . If the go-cart and rider have a total mass of 180 kg, **determine** the net force was needed to cause this acceleration? (4 marks)
 - The actual force applied by the tires of the go-cart to the track during the acceleration in part (c) was 1680 N. **Determine** the force of friction (air resistance, rolling friction) acting against the motion of the go-cart. (3 marks)
 - As the cart approached turn D, the driver over-braked and locked up all four wheels. The cart slowed down at 14.5 m/s^2 . **Determine** the coefficient of kinetic friction for the go-cart's tires sliding on the asphalt track. (3 marks)
4. A car with a mass of 1700 kg accelerates at a rate of 1.70 m/s^2 . The magnitude of the force of friction opposing the motion of the car is 950 N.

- **Determine** the horizontal force the car's tires exert on the roadway. (3 marks)
- Is the force you found in part (a) the force that moves the car forward? **Discuss**, making reference to one of Newton's laws of motion. (3 marks)



5. The book shown below has a weight of 5.40 N, and it is stationary on a board that is angled at 15.0° to the horizontal.

- **Determine** the normal force on the book (perpendicular force between book and board) and the force of friction.
- **Describe** what is going to happen to the book if the angle of the board is increased.

As part of your response **sketch** a labeled free body diagram, **sketch** a vector addition diagram and **state** all necessary physics concepts, formulas and substitutions. (12 marks)

6. A force of 25.3 N, north and 12.4 N, west act on a box. **Determine** the net force on the box.

Marks will be awarded based on your vector diagrams, the physics that you use, and the mathematical treatment you provide. (10 marks)

APPENDIX K

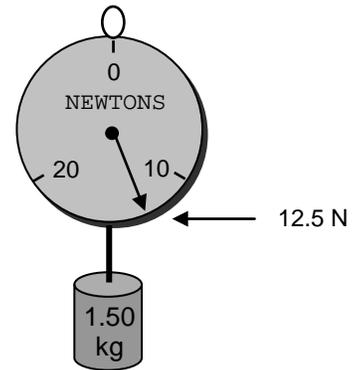
GRAVITATIONAL FORCES AND FIELDS QUIZ

APPENDIX K: GRAVITATIONAL FORCES AND FIELDS QUIZ

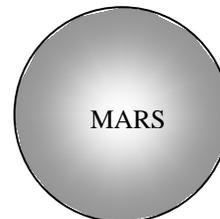
PHYSICS 20
Gravity QUIZ

NAME:

1. A space traveler on a distant planet measures gravitational field strength using the apparatus sketched at right. What does she determine as the value of local gravity on the planet? (3)



-
2. The sketch at right shows the planet Mars.
- a) Use the diagram at right to sketch the gravitational field around Mars. (1)
- b) Explain the meaning of the term **field** as used in science. Give an example of a vector field other than gravity; of a scalar field. (4)



- c) Mars has a mass of 6.42×10^{23} kg and a radius of 3.40×10^6 m (that is, at the surface of the planet you would be 3.40×10^6 m from Mars' centre.) Find the gravitational field strength on Mars' surface. (3)
- d) If you have a mass of 55.0 kg, what would you weigh on the surface of Mars? (3)

3. A lunar exploration vehicle has a weight on earth of 3500 N. It is sent to the moon, where $g = 1.62 \text{ N/kg}$.

a) What will the vehicle weigh on the moon?
(3)

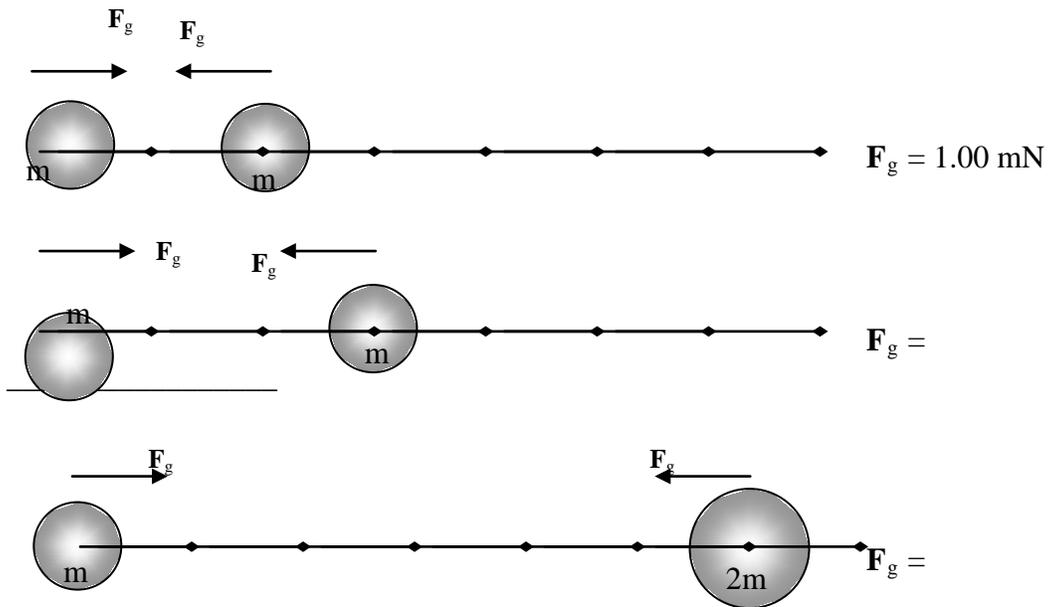
b) What is the mass of the vehicle on the moon? (3)

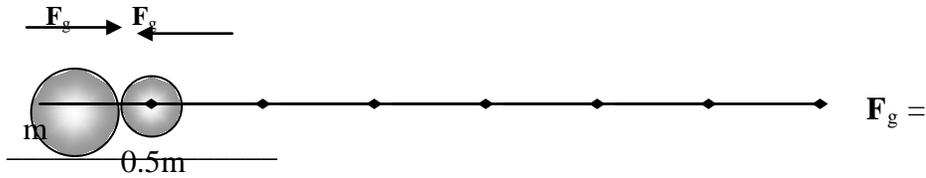
4. Two supertankers, each of mass $2.45 \times 10^8 \text{ kg}$, are moored (tied together) with their centres 50.0 m apart.

a) Find the gravitational force of attraction between the two supertankers. (3)

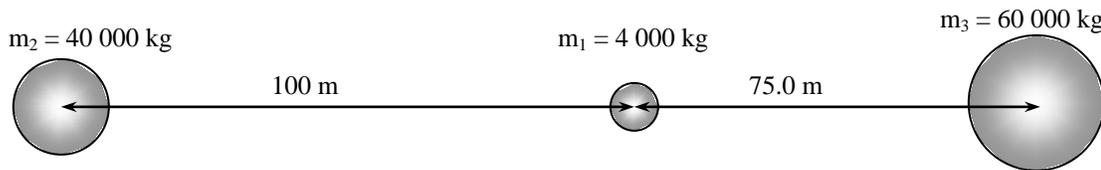
b) If the mooring of one tanker breaks and friction is neglected, at what rate will this tanker accelerate towards the second one? (4)

5. Use the sketches to find the force of gravitational attraction between each pair of spheres. The value of F_g is given for the first pair. Force vectors are not drawn to scale. (3)

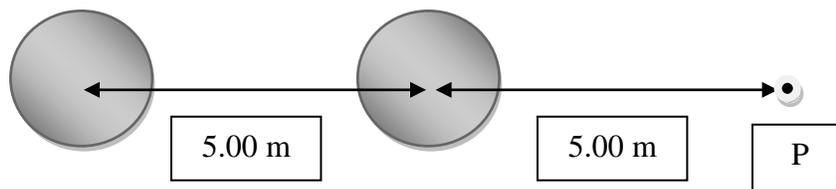




6. Find the net gravitational force (magnitude and direction) acting on m_1 in the sketch below; assume no other forces act. As part of your response, draw a free body diagram, vector diagram, state your directional logic and state all formulas and physics principles. (10)



7. Determine the net gravitational field at point P produced by the two 50 kg masses shown below. As part of your response, draw a situational diagram, vector diagram, state your directional logic and state all formulas and physics principles used. (10)



APPENDIX L

SUMMATIVE UNIT EXAM

APPENDIX L: SUMMATIVE UNIT EXAM

Physics 20 Unit 2 Exam

This exam includes 21 multiple-choice questions (worth one mark each) and 6 numerical response questions (worth one mark each). The exam also includes written response questions worth 16 marks, for a total raw score of 43 marks.

YOU MAY WRITE ANYWHERE IN THIS BOOKLET.
YOU MAY USE A PHYSICS 20 DATA SHEET ON THIS EXAM.

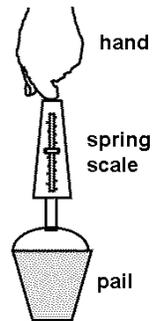
- ❖ PLEASE WRITE YOUR NAME ON THE ANSWER SHEET AND THIS BOOKLET.
- ❖ You may use a calculator on this exam; if it is a graphing calculator, it may be cleared by your teacher as the exam begins. REMEMBER THAT NO MUSIC SOURCES ARE ALLOWED DURING THE EXAM; no earbuds, please!
- ❖ All answers for multiple-choice questions should be entered on the multiple choice answer sheet; multiple-choice questions are worth one mark each.
- ❖ All answers for numerical response questions should be entered in the appropriate section on the multiple-choice answer sheet. Numerical response questions are worth one mark each. Your answer must be a POSITIVE number; the first digit should be entered in the furthest LEFT BOX of the answer blank. If your answer has a decimal value as well as a whole number value, it should be in the form 1.23 or 12.3. If your answer is only a decimal value, it should be in the form 0.12 – include the leading zero.
- ❖ Marks for written response questions are given with each question. For written response questions, be sure you have included a formula statement (if needed), shown correct rearrangement and substitution into the formula (if needed), stated an unrounded answer, and given a correctly rounded, final answer including appropriate units. If a question requires a vector diagram, be sure it is correctly labeled.

Do your best on this exam and good luck!

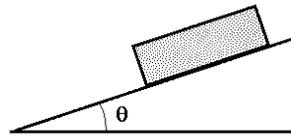
1. What is the difference between a scalar quantity and a vector quantity?
- A scalar quantity has no direction whereas a vector quantity has a direction.
 - A scalar quantity is used in the study of kinematics whereas a vector quantity is used in the study of dynamics.
 - A scalar quantity has a magnitude and a direction whereas a vector quantity has only a magnitude.
 - A scalar quantity has magnitude, units, and a direction whereas a vector quantity has only magnitude and units.

2. As sketched at right, what forces are acting on the pail when hung from a spring scale supported by a hand?

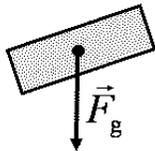
- the force of gravity [down] only
- the elastic force of the spring [up] only
- both the force of gravity [down] and the elastic force of the spring [up]
- the force of gravity [down], the elastic force of the spring [up], and the force of the hand [up]



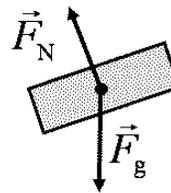
3. A stationary block is at rest on a rough inclined plane, as shown. If \vec{F}_g is the force of gravity, \vec{F}_N is the normal force, and \vec{F}_f is the force of friction, which free-body diagram below is correct?



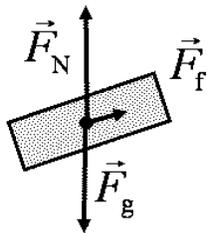
A.



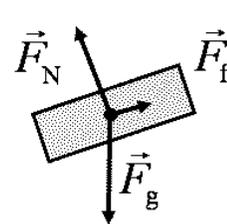
C.



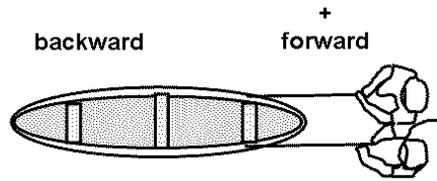
B.



D.



4. Two people, A and B, are dragging a canoe across a level beach using light ropes. Person A applies a force of 40.0 N and person B applies a force of 80.0 N. The force of friction exerted by the beach on the canoe is 100 N. What is the net force on the canoe?



- A. 220 N [forward] C. 20.0 N [forward]
 B. 220 N [backward] D. 20.0 N [backward]

5. Which of the following statements is correct for an object moving horizontally at a constant velocity?

- A. The object has a constant net force greater than zero acting on it.
 B. The force of gravity acting on the object is zero.
 C. All the horizontal forces acting on the object balance each other.
 D. The normal force acting on the object is zero.

6. Which of the following is the **best** description of inertia?

- A. Inertia is the property of an object that resists velocity.
 B. Inertia is the property of a body that resists acceleration.
 C. Inertia is the property of an object that resists motion.
 D. Inertia is another name for the weight of an object.

7. While moving horizontally forward at constant velocity on a snowmobile, the rider throws a ball straight up so that it reaches a height of 5 m. Ignoring air resistance, where will the ball land?



- A. back in the rider's hand C. behind the rider's hand
 B. in front of the rider's hand D. behind the snowmobile

8. An object is given an acceleration of 2.50 m/s^2 [60°] by a net force of 5.00 N [60°]. The mass of the object is:

- A. 0.500 kg C. 12.5 kg
 B. 2.00 kg D. 7.50 kg

Numerical Response

Enter your answer in the space provided on the answer sheet.

1. A girl is pushing a 500-kg refrigerator across a level floor. She exerts a constant force of 200 N to maintain a velocity of 0.100 m/s [270°]. When the girl stops pushing, the refrigerator will come to rest in a time of _____ s. (Record your **decimal** answer in the correct space on the answer sheet.)

4. Match the number of each type of force above with its description given below. (Record all **four digits** of your answer on the answer sheet.)

Types of Forces	
1	Net force
2	Friction force
3	Applied force
4	Normal force

- Force that acts perpendicular to a common surface ___ (Record in the **first** column.)
- Vector sum of all forces acting on an object ___ (Record in the **second** column.)
- Force that opposes an object's motion ___ (Record in the **third** column.)
- Force that acts parallel to a common surface ___ (Record in the **fourth** column.)

12. Which statement is correct for the gravitational mass of an object?
- The gravitational mass of an object is different on the surface of the Moon than on the surface of Earth.
 - The gravitational mass of an object is numerically equal to its weight but has different units.
 - The gravitational mass of an object is measured by comparing its weight to that of a standard mass.
 - The gravitational mass of an object is measured using a calibrated spring balance to accelerate the object.
13. The gravitational force of attraction between two spheres of mass 2.0 kg each, whose centres are separated by 2.0 m, is
- 4.0 N
 - 6.7×10^{-11} N
 - $2.0 \times 6.7 \times 10^{-11}$ N
 - $4.0 \times 6.7 \times 10^{-11}$ N
14. Two students are sitting in a school cafeteria eating lunch, separated by a distance Δd . They move so that the distance between them is now one-quarter as great as before. The force of gravitational attraction between them is now
- one-sixteenth as great
 - one-quarter as great
 - four times greater
 - sixteen times greater
15. A physics student stands on a bathroom scale, calibrated in newtons, while riding in an elevator. How will the reading on the bathroom scale compare to the normal reading for the following sequence of the elevator's motion?
- Elevator starts to descend; elevator descends at constant velocity; elevator stops descending.
- heavier; normal; heavier
 - lighter; normal; heavier
 - heavier; normal; lighter
 - lighter; normal; lighter

Numerical Response

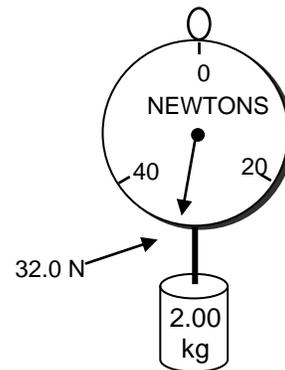
Enter your answer in the space provided on the answer sheet.

5. In 1971, Alan Shepard became the first astronaut to golf on the Moon. If the Moon's gravitational field strength is 1.62 N/kg , the weight of a 45.0-g golf ball on the Moon is $a.bc \times 10^{-d} \text{ N}$. The values of a , b , c , and d are ____, ____, ____ and _____. (Record all **four digits** of your answer on the answer sheet.)

16. Which of the following statements about gravitational force, F_g , is **not** correct?
- Gravitational force is an attractive force only; it is never repulsive.
 - Gravitational force is the weakest of the fundamental forces.
 - Gravitational forces vary directly with the masses of objects.
 - Gravitational forces vary inversely with the distance between objects.

17. Based on the experiment sketched at right, the local value of g is

- 16.0 N/kg
- 32.0 N/kg
- 64.0 N/kg
- 10.0 N/kg

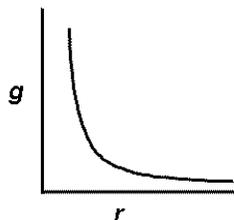


18. A student has a true weight of 608 N . While riding in an elevator, he experiences an increase in his weight of 50.0 N . At that moment, the motion of the elevator is

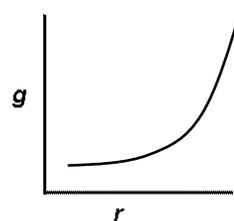
- A constant upwards velocity of 5.10 m/s
- A constant downwards velocity of 5.10 m/s
- An acceleration upwards of 0.807 m/s^2
- An acceleration downwards of 0.807 m/s^2

19. Which of the following graphs best represents the gravitational field strength, g , versus distance from the earth's centre, r ?

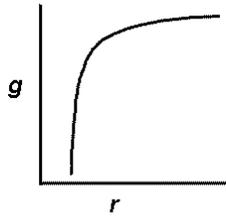
A.



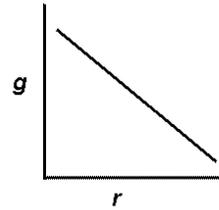
C.



B.



D.



20. An astronaut experiences a force of gravity on Earth of 800 N. Neptune has 17 times the mass and 3.9 times the radius of Earth. What (approximately) would the astronaut weigh, in newtons, on Neptune?

A. $800 \times \frac{17}{3.9}$
 B. $800 \times \frac{3.9}{17}$

C. $800 \times \frac{17}{15}$
 D. $800 \times \frac{15}{17}$

21. Two bags of identical steel bearings are suspended one metre apart. Which of the following changes would double the gravitational force that one bag exerts on the other?

- A. doubling the number of bearings in one bag
 B. doubling the number of bearings in both bags
 C. decreasing the separation of the bags by one-half
 D. decreasing the separation of the bags by one-quarter

Use the information below to answer the next two questions.

The planet Uranus has a mass of 8.68×10^{25} kg and a radius of 2.56×10^7 m.

Written Response

Be sure to state formulas as needed, show your work, use correct notation and correctly round final answers.

22. Determine the gravitational field strength on the surface of Uranus. (2 marks)

Numerical Response

Enter your answer in the space provided on the answer sheet.

6. On the surface of Uranus, an astronaut with a mass of 85.0 kg would have a weight of _____ N. (Record your **three-digit** answer on the answer sheet.)
-

Written Response

Be sure to state formulas as needed, show your work, use correct notation and correctly round final answers.

23. A student tests the acceleration of his 950-kg automobile, and finds that it can go from 0 to 100 km/h (27.8 m/s) in 8.52 s. The engine provides an applied force of 10.7 kN (200 hp).

- a) Find the car's acceleration. (2 marks)
-

- b) What is the average force of friction in this case? (2 marks)
-

- c) Without changing the force of the engine, what could be done to increase the acceleration of the car? (1 mark)

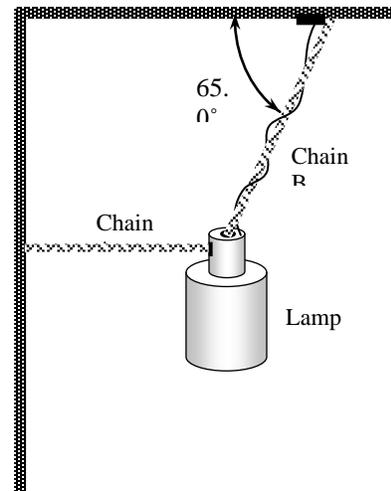
24. Following a freezing rain, a child with a mass of 32.0 kg runs and slides on a horizontal driveway that is coated with ice. The child runs with a speed of 2.50 m/s, slides, and slows down at 0.900 m/s^2 before finally stopping.

- a) How far does the child slide? (2 marks)

- b) What is the coefficient of kinetic friction between the child's shoes and the driveway? (2 marks)

25. The sketch to the right shows a lamp suspended from two chains in the corner of a room. The lamp has a mass of 2.50 kg.

a) Sketch a free-body diagram of the forces acting on the lamp. Label the forces. (2 marks)



b) Determine the tension forces in chain A and in chain B. (3 marks)

APPENDIX M

STUDENT INTERVIEW QUESTIONS

APPENDIX M: STUDENT INTERVIEW QUESTIONS

POST UNIT INTERVENTION STUDENT INTERVIEWS

Instructions

The following questions are to be asked of the student subjects after completion of the unit objectives.

The following statements are to be read to student subjects prior to commencing the interview:

Participation in this interview is voluntary and you can choose to not answer any question that you so not want to answer, and you can stop at any time.

Your participation or non-participation will not affect your grade or class standing.

Questions

1. Do you enjoy physics? Why or why not?
2. Do you find physics a difficult subject? Why or why not?
3. Did you enjoy learning the physics concepts of this unit using the computer simulations? Why or Why not?
4. Can you evaluate the seven simulations we have used this unit. In other words, is there one or two simulations you thought were better than the others? Provide some reasons why.
5. Did the simulations help you visualize the ideas and concepts of Newtonian mechanics? Explain how.
6. Would you use other computer simulations to help you understand and solve physics concepts and problems outside of class (i.e. when doing homework)? Explain how.
7. What did you like about using the simulations? Explain
8. What did you not like about using the simulations? Explain.
9. Would you like to 'do' more physics using the computer simulations? Why or why not.
10. How did the computer simulations affect your understanding of the physics concepts? Explain.
11. Anything else you want to tell me regarding the use of computer simulations for learning physics?