

APPLICATION OF AN INQUIRY- BASED
INSTRUCTION MODEL IN MECHANICS
LABS

by

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ABSTRACT

This project addresses the issue of motivating students to develop problem-solving and critical-thinking skills. The methods developed for doing so are demonstrated as being grounded in educational literature. The materials created during the project are presented and explained. These materials have been created for an inquiry-based physics lab which involves students in the scientific method and reasoning for their activities in the lab. Important aspects of grading and administering inquiry-based assignments are discussed. The lab procedure has been tested on a limited scale and the results of initial testing are discussed. Suggestions are made for further testing and refinement of the materials.

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GLOSSARY

Control. The particular value of an independent variable used for the purposes of an experiment.

Dependent Variable. The variable which is to be tested during an experiment. The value of which relies on the value of other variables.

Independent Variable. A variable which is subject to change within an experiment in order to observe the results.

Inquiry-Based Method. Instructional method that employs the use of critical-thinking and deductive reasoning to involve students in the subject matter.

Newton's 2nd Law. "The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object." (The Physics Classroom)
Mathematically: $\vec{F} = m \vec{a}$

Scaffolding. Appropriate structure provided by an educator to keep students focused without restricting educational exploration

WPI. Abbr. Worcester Polytechnic Institute

INTRODUCTION

Preamble

Regardless of the individual interests of students, the problem-solving skills learned in areas like physics and the sciences will become invaluable in a student's future education and beyond. This project was aimed at inspiring an interest in problem-solving methodology and critical thinking for just this reason. It is our hope, that by reinforcing problem-solving skills in a student's physics education, students will create a firm foundation upon which continuing education may build.

Problem Statement

The problem to be addressed is that physics students do not have a strong motivation to learn problem solving skills and explore the principles involved in the curriculum.

Proposed Solution

The solution proposed is to construct lab procedures that provide adequate structure for students while motivating them to explore the subject matter and develop problem solving skills. For this purpose, the inquiry-based model will be adapted to a college physics lab.

Scope of the Project

The scope of this project is to gather research on similar types of curriculum from education research studies and use this research to develop a feasible curriculum. The product will be a lab procedure developed to encourage students to explore physics concepts and improve their problem solving skills. In addition, the research will be used to develop a method for evaluating the success of the lab procedures in achieving the proposed goal. The evaluation procedure should provide the criteria for determining the success of the labs in respect to the goal statement and some methods for doing so.

Research

In preparation for creating the inquiry-based lab materials, research was conducted wherein educational literature was reviewed to learn more about implementation of the inquiry-based approach in teaching.

Some sources provided generalized information on the topic of inquiry-based education and resources for further research on the subject. The article, "Effects of Inquiry-based Learning on Students' Science Literacy Skills and Confidence" (Brickman et al.), was one such source. As was the article, "Lessons learned about implementing an inquiry-

based curriculum in a college biology laboratory classroom" (Armstrong, Norris, et al.), from the *Journal of College Teaching*.

Of particular influence in the creation of the lab materials were two sources; "What Makes Swing Time? A Directed Inquiry-Based Lab Assessment" (Donaldson, Nancy L., and A. Louis Odom.) and "Model Based Inquiry in the High School Physics Classroom: An Exploratory Study of Implementation and Outcomes" (Campbell et al.) from the *Journal of Science Education and Technology*. The former provided an example of a laboratory lesson plan and grading criteria which was adapted as a template for creating the inquiry-based lab materials. The latter provided examples of a lesson plan in a more traditional style alongside an inquiry-based style of instruction which was helpful in illustrating the way in which a subject could be transferred to the inquiry-based instruction method.

Finally, "Managing Inquiry-based Classrooms" (Wolfgang, Christie Nicole.) supplemented the lab planning by providing important insights into the nature of an inquiry-based classroom and assessment of student performance in this environment.

Summary of Inquiry-Based Approach

The principle behind the inquiry-based approach is to encourage critical-thinking and curiosity about the subject at hand. In this way, the inquiry-based method is less of a demonstration of ideas and more of a guide to student exploration. The hope is that, by exploring the principles proposed in their courses instead of simply listening to facts and explanations, students become engaged in the material in a way that enforces understanding and encourages further investigation.

Application in College Physics Courses

In my experience, a key element for success in college physics courses is to develop a firm understanding of the physical principles and laws involved in a given situation. The kind of understanding required to apply the knowledge of physics to further problems cannot be gleaned from simply attending lectures, taking notes, and following instructions in lab. Repeated investigation and application of physical principles in problem-solving situations, however, is helpful in developing understanding. For this reason, the inquiry-based method of physics education aims to inspire exploration of the laws and theories of physics and exercise critical thinking and problem-solving.

In the proposed lab plan, emphasis is put on answering problems about the nature of the lab procedure in the pre-lab so that students understand why they are taking the steps they are taking in the lab. Similarly, students are asked to answer questions during the lab which require critical thinking and encourage the development of problem solving skills. Here, pursuing an understanding of how to apply physics in a practical way is

encouraged by asking students to apply their knowledge and explore the principles and evidence further.

CHAPTER 1

METHODOLOGY

Objectives

The aim of this project was to develop a laboratory assignment to encourage the development of problem solving skills and the application of physics principles. The inquiry-based model of instruction was used to develop adequate scaffolding for students while requiring exploration of the subject matter and critical thinking. For this purpose, the inquiry-based models described by the sources reviewed during the research stage of the project were adapted to existing physics curriculum.

Constraints

The assignment developed was intended to be used in a college physics course wherein the students have been introduced to the concept of Newton's 2nd Law. The purpose was to provide a lab procedure which could be performed in a 50 minute lab period with supplemental questions to be assigned before and during the lab. All of these materials are designed to meet the objectives described previously. A procedure was also developed using available materials to perform an appropriate experiment for demonstration of the principle of Newton's 2nd Law.

Using Pre-lab Assignments

A pre-lab assignment supports the objectives of the project by encouraging students to understand the scientific method as it is applied to the lab exercise. To this end, the pre-lab exercise asks students to think about concepts such as the principles under investigation, independent and dependent variables, experimental controls, and appropriate data collection. The intention is that these questions will reinforce problem-solving skills and motivate students to understand the reasons for the instructions given in the lab procedure. Ultimately, students should be able to use similar methodologies in further investigation of scientific principles and for problem solving within and beyond the classroom.

Guiding Questions as an Inquiry-Based Instruction Method

Given the constraints of a 50 minute lab period and the intended use of the lab in an introductory level physics course, an open-ended experimental type inquiry method was deemed impractical as it would not provide the scaffolding necessary to guide students through the pertinent material in an appropriate timeframe. According to the literature review conducted as well as the suggestion of the professors involved in this project, the

use of guiding questions was implemented as a means to provide room for students to explore the scientific principles involved in the experiment while maintaining enough guidance to keep the classroom focused on the task at hand. The scaffolding provided through the guiding questions method helps to make the idea viable for a 50 minute lab period with the anticipated audience.

Lab Instructions

The lab instructions were developed such that they would appear similar to the current formatting of lab instructions used by the physics department at WPI so that when the instruction method is evaluated for further development, the difference in basic formatting would have a minimal impact on the outcome of student evaluations. In the case of evaluations, the formatting is an independent variable and thus should be controlled as best as possible. Specifically, the instructions were formatted to fit the web page formatting of the current instructions with links to each step in the experiment and each step occupying no more than one page so that scrolling the page up and down is not necessary while performing the lab exercise.

Experimental Procedure

The experimental procedure upon which this lab is based began as a lab assigned during an introductory physics class which I took at Northshore Community College. The original experiment used a bathroom scale and the elevator at the college. Groups took turns riding the elevator with a group member on the scale and recording the fluctuations in the weight displayed by the scale as the elevator accelerated during a trip upward and downward. This procedure was refined and adapted so that a similar experiment could be performed in the laboratory using equipment available in the physics laboratories at WPI. The same basic experiment could be performed in a number of ways with little impact on the inquiry-based instruction method outlined in the pre-lab exercise and the guiding questions. Similarly, the instruction methods may be adapted to any number of experiments demonstrating any number of scientific principles.

CHAPTER 2

RESULTS

Materials Developed

Please note that the complete, unabridged collection of developed materials is available in Appendices A and B which contain the student and instructor versions respectively.

Pre-Lab Assignment

Figure 1. Pre-Lab Exercise Instructor's Guide with Model Responses

Using Newton's 2nd Law and Free-Body Diagrams to Determine Acceleration of an Elevator.

Pre-lab Exercise: (To be completed prior to lab)

Timeline: 10 minutes of discussion may be needed in class before assigning the pre-lab exercise to explain the format of the lab and the importance of completing the pre-lab before the lab period.

The pre-lab may take students 1-2 hrs. individually.

Scenario: We must determine the acceleration of an elevator empirically using experimental data. No accelerometer is available. However, a force plate or scale and the elevator are available.

Materials: Force plate or scale, a mass of a predetermined size, an elevator

For the instructor: Model responses should be given to students after they have completed their pre-lab exercise and the pre-lab has been assessed (assessment procedure is another area which needs development). It may be helpful to spend some time in conference discussing the pre-lab results before the lab. Students should then have a chance to make revisions to their worksheets before the lab period.

1. How could data from a force plate or scale be used to determine acceleration of the elevator?

Model Response:

From a FBD of an object in the elevator and Newton's 2nd Law, it is apparent that the acceleration of the elevator and the forces acting on the object will be related. (It may be helpful to do this question last.)

2. How will acceleration of the elevator affect the apparent weight of a body on a

force plate or scale? What effect does acceleration have on apparent weight in this situation?

Model Response:

When the elevator accelerates upward, the apparent weight should increase. When the elevator accelerates downward, the apparent weight should decrease. The weight of the object should remain constant (near earth's surface). The scale or force plate will be measuring normal force which will be the apparent weight.

3. What are the independent variables?

Model Response:

The acceleration of the elevator, mass of the object (and therefore weight).

4. What are the dependent variables?

Model Response:

Apparent weight or normal force.

5. What conditions need to be held constant?

Model Response:

Mass of the object on the force plate or scale, the particular elevator used, the total occupancy of the elevator (nobody should enter or leave the elevator and the same people should ride the elevator until all data is collected)

6. What controls should be used?

Model Response:

An object of a certain mass. That mass should be: (Possibly determined by the instructor and given in a materials list.)

7. Write a procedure that you will use to determine the acceleration of the elevator. This should be a step-by-step procedure that someone else could follow to arrive at similar results.

Model Response:

- a. Set up the force plate or scale on the floor of the elevator with the mass on top of it.*
- b. Record the initial reading from the scale or from the force plate.*
- c. Ride the elevator either up or down and record the changes in the scale reading as well as the direction of travel of the elevator.*
- d. Ride the elevator the opposite direction and record the same data.*
- e. Repeat c. and d. and record data for each trial.*

f. Calculate the acceleration of the elevator using the data collected.

8. Create a spreadsheet wherein you will record the necessary data.

Model Response:

This could be done in excel or by hand.

<i>Elevator Direction</i>	<i>Beginning, middle or end of ride.</i>	<i>Mass of object on scale</i>	<i>Force reading (maximum or minimum)</i>	<i>Acceleration of the elevator (measured)</i>	<i>Acceleration of the elevator (calculated)</i>
<i>Up</i>	<i>Beginning</i>				
	<i>Middle</i>				
	<i>End</i>				
<i>Down</i>	<i>Beginning</i>				

9. Draw any necessary Free-Body Diagrams and derive any equations you may need to calculate the acceleration of the elevator using the data you collect.

Model Response:

Choosing upward as the positive direction. Note: FBD provided in the full version in Appendix B.

$$\Sigma \vec{F} = m\vec{a} \Rightarrow -\vec{F}_g + \vec{F}_N = m\vec{a} \Rightarrow \vec{a} = \frac{(-\vec{F}_g + \vec{F}_N)}{m}$$

Lab Instructions

Figure 2. Lab Instructions to be Distributed to Students. Note: The instructions have been edited for the purposes of brevity. An unabridged version of the lab instructions may be found in Appendix A.

Using Newton's 2nd Law and Free-Body Diagrams

P r e a m b l e

This lab procedure is accompanied by a set of instructions for pre-lab preparations and a set of questions which are aimed at determining the strength of your understanding of the material involved. Since it is assumed that you will be able to follow the lab procedure by reading the instructions, your grade will be based on your ability to communicate the

principles involved in this experiment rather than your performance of the lab procedures.

Please note that for the purposes of this lab, the elevator will be simulated by the devices as described in the procedure. From this point forward in the instructions and the guiding questions, the simulated elevator will be referred to as the elevator.

O v e r v i e w

The objective of this lab is to demonstrate an understanding of Newton's 2nd Law and the importance of using free-body diagrams in problem solving. This will be achieved by using Newton's 2nd Law and free-body diagrams to find the acceleration of an elevator and exhibiting an understanding of the procedure used to discover this information in your answers to the accompanying questions.

You will need to collect the information you decided was necessary during the lab period. If the pre-lab was completed, you should have a table (or Excel spreadsheet) similar to the following in which to record experimental data during the lab period.

<i>Elevator Direction</i>	<i>Beginning, middle or end of ride.</i>	<i>Mass of object on scale</i>	<i>Force reading (maximum or minimum)</i>	<i>Acceleration of the elevator (measured)</i>	<i>Acceleration of the elevator (calculated)</i>
<i>Up</i>	<i>Beginning</i>				
	<i>Middle</i>				
	<i>End</i>				
<i>Down</i>	<i>Beginning</i>				
	<i>Middle</i>				
	<i>End</i>				

P a r t I, P r e p a r a t i o n

- You should have drawn some free-body diagrams and derived some equations before coming to lab.
- Now, sketch a prediction for the shape of the graph of the measured force during an

elevator ride going up and an elevator ride going down (on your guiding questions sheet).

Part II, Force Measurements

- Firstly, the switch on the force sensor needs to be set to the ± 50 N setting in order to use a 1kg. hanging mass.
- The sensor must be zeroed in Logger Pro before hanging the mass on the sensor. Once the force value is zeroed you may hang the mass on the sensor and check to see that the force value is close to what you expected.
- Then a trial should be made for the elevator travelling upward. Collect data while simulating an upward moving elevator. In order to simulate an elevator moving upward, students will pull down on the counterweight stopping before the counterweight reaches the floor or the force sensor reaches the pulley. Record the appropriate data in your table.
- Finally collect data for the elevator travelling downward. To simulate a downward moving elevator, students should start with the counterweight near the floor and allow the counterweight to rise in a controlled fashion until the weights hanging from the sensor are near the floor. Record the appropriate data in your table.

Part III, Calculate Acceleration

- Use the maximum and minimum values of the force data collected during the trials to calculate the acceleration of the elevator. Record the appropriate data in your table.
- Create a graph of the acceleration of the elevator in Logger Pro using the data collected during the experiment.

Guiding Questions

Figure 3. Guiding Questions Instructor's Guide with Model Responses.

FBD Lab Guiding Questions

1. Sketch your prediction for the shape of the graphs of measured force during an elevator ride going up and an elevator ride going down here:

Going Up:	Going Down:

2. If you need to determine the acceleration of the elevator during an upward trip and a

downward trip, how many free-body diagrams do you need to solve this problem? Why? Also, include your free-body diagram(s) below.

Model Response: The problem can be solved with just one free-body diagram. However, a free-body diagram representing the upward moving case and the downward moving case separately may be convenient to simplify some of the arithmetic.

3. How did you decide what information needed to be recorded during the lab?

Model Response: Free-body diagrams should have been drawn and equations should have been set up using Newton's 2nd Law. Once this has been done, it should be clear what needs to be recorded during the lab in order to solve the equations for the acceleration of the elevator.

4. What relationship do you expect to see between the graphs of measured force and acceleration? Explain this relationship using Newton's 2nd Law.

Model Response: The graphs of force and acceleration should have similar shapes because the acceleration of the elevator and the force measured are directly proportional. According to Newton's 2nd Law: $F = ma$. In this case, mass remained constant. So, force and acceleration change proportionally during the elevator ride.

5. Did you see the relationship you expected to see if/when acceleration was measured? Explain.

Model Response: If students had a chance to measure acceleration with an accelerometer or a demonstration was provided using an accelerometer to compare the graphs of acceleration and force, the graphs should have a similar shape exemplifying the proportionality of force and acceleration.

6. Can we use the same equation to calculate the acceleration of the elevator in both the upward and downward direction? If so, show how. If not, what do we need to change?

Model Response: The same equation applies no matter what the direction of the elevator is. The direction of travel will be represented by a positive or negative result depending on the free-body diagram and chosen coordinates. Students should include free-body diagrams and equations to make their point. If students made separate FBDs and chose coordinates differently for opposite travel directions, their response is acceptable as long as they explain their reasoning.

7. If we were to use an object of twice the mass to perform the same experiment, how would you expect the results to change?

Model Response: Assuming the acceleration remains the same, we would expect the observed forces to be doubled. We could also speculate that the force the elevator applies is constant. In this case, as long as the students reasoning involving Newton's 2nd Law is correct and their explanation is clear, full credit may be given.

Administering an Inquiry-Based Assignment

The role of the instructor in an inquiry-based classroom is in some ways dissimilar to the traditional role of the instructor in a science classroom. The inquiry-based method of instruction relies less on verbal transmission of knowledge and places more reliance on experience to support understanding. For this reason, the instructor in an inquiry-based classroom becomes more of a facilitator; with less lecturing necessary and more focus on offering guidance from an experienced point of view. It may be appropriate in most cases for an instructor in an inquiry-based classroom to never directly answer a student question but instead to guide the student toward the answer with pointed questions.

The idea is that the students will learn the material through their own logical and critical exploration through the medium of the Pre-Lab exercise and the Guiding Questions. The instructor can of course be helpful in guiding students during the lab by providing further guiding questions in a small group or one-on-one as students are performing the lab. This kind of dialog between students and teachers is the ideal form of communication in an inquiry-based method. Instructors should, ideally, be able to guide students in their thinking by helping students to restate the problem they are struggling with in a way that the student can come to their own conclusion through logical analysis. This is in contrast with providing the students with a statement of knowledge about the particular problem.

For example, a student may struggle with the idea that the weight measured by the force sensor changes as the elevator accelerates. Instead of stating Newton's 2nd Law and providing a mathematical explanation, the instructor in an inquiry based classroom may be more helpful by asking the student what Newton's 2nd Law says about force and acceleration as well as asking what the force sensor is actually measuring and how that fits into the principle of Newton's 2nd Law. In this way, the student must use logic and critical thinking to solve the problem and thus the student gains an experiential knowledge of the principle.

Grading an Inquiry-Based Assignment

The focus of the inquiry-based approach is on problem-solving and critical thinking. However, it is also important that the instruction method help students to solidify the concepts being explored. For these reasons, the assessment of students' work in an inquiry-based curriculum should be designed to encourage problem solving and critical thinking as well as recognizing students' understanding of the course material. An example grading guide has been produced to demonstrate how the Pre-Lab assignment and the Guiding Questions portion of the lab assignment should be graded in accordance with the goals of the inquiry-based method. In general, the "best" answer demonstrates that a firm understanding of the material was used by the student to work through the situation logically and solve the problem at hand in a reasonable and thoughtful way. Various degrees of credit are then awarded for solutions which demonstrate appropriate levels of critical thinking and understanding. A system of points has been assigned in the example assessment criteria. This points system, however, is entirely customizable and the quantity of points given for each level of understanding is of course far less important than the idea that the answers demonstrate varying levels of understanding.

Pre-Lab Assignment Grading Criteria

Figure 4. Grading Criteria for Pre-Lab Assignment

Pre-Lab – Maximum 18 points

Note: The grading scheme shown in the first example is suggested as a grading scheme throughout.

1. **How could data from a force plate or scale be used to determine acceleration of the elevator?**
 - Theory (Newton's 2nd Law) and Free-Body Diagram accurately represent the situation and the relationship between the forces on the object and the acceleration of the elevator are described. **(2)**
 - Theory and Free-Body Diagram accurately represent the situation. **(1)**
 - A Free-Body diagram is presented. But, the diagram or the theory is incorrect. **(1/2)**
 - No Free-Body diagram or theory is presented **(0)**
2. **How will acceleration of the elevator affect the apparent weight of a body on a force plate or scale? What effect does acceleration have on apparent weight in this situation?**
 - A prediction about the relationship between the apparent weight of the object and the acceleration of the elevator is presented which need not be entirely correct though it should be relevant to the experiment.
 - A prediction is made which is not entirely relevant to the experiment but shows strong effort in reasoning.
 - A prediction is made which shows little effort in reasoning.
 - No Prediction is made.

3. **What are the independent variables?**
 - All relevant independent variables are listed.
 - Some of the relevant independent variables are listed.
 - Some variables are listed. But, they are not the relevant independent variables.
 - No variables are listed.
4. **What are the dependent variables?**
 - All relevant dependent variables are listed.
 - Some of the relevant dependent variables are listed.
 - Some variables are listed. But, they are not the relevant dependent variables.
 - No variables are listed.
5. **What conditions need to be held constant?**
 - All necessary conditions are described.
 - Some of the necessary conditions are described.
 - Conditions are described. But, they are not relevant.
 - No conditions are described.
6. **What controls should be used?**
 - All necessary controls are described.
 - Some of the necessary controls are described.
 - Controls are described. But, they are not relevant.
 - No controls are described.
7. **Write a procedure that you will use to determine the acceleration of the elevator. This should be a step-by-step procedure that someone else could follow to arrive at similar results.**
 - The procedure contains step-by-step instructions that could be used to collect the necessary data. The procedure contains no major flaws that would affect the data in such a way that the situation is misrepresented.
 - The procedure contains step-by-step instructions that could be used to collect the necessary data. Some major step is excluded or some misstep is introduced which will cause irrelevant results.
 - A step-by-step procedure is presented. However, it is misguided.
 - No step-by-step procedure is presented.
8. **Create a spreadsheet wherein you will record the necessary data.**
 - A spreadsheet has been created which includes space to record all necessary data. The spreadsheet may also include space for calculations and space to record controls.
 - A spreadsheet has been created which includes space for some of the necessary data. But, some important factor is omitted.
 - A spreadsheet is created. But, it does not contain space for any of the

relevant data.

- No spreadsheet is presented.

9. Draw any necessary Free-Body Diagrams and derive any equations you may need to calculate the acceleration of the elevator using the data you collect.

- Appropriate FBDs are presented and derivations of the proper equations are shown from known theories and laws that can be used to accurately calculate the acceleration of the elevator.
- Appropriate FBDs are presented and derivations are shown that incorporate appropriate theories. But, they include algebraic errors. **Or**, the results of derivations are shown correctly. But, the derivation has not been included.
- FBDs are attempted and theories which may be used have been presented or an attempt at derivation has been made. However, the theories or derivations are irrelevant or erroneous.
- No FBDs are included or FBDs are inappropriate and no relevant theory is presented or no attempt is made to derive equations.

Guiding Questions Grading Criteria

Figure 5. Grading Criteria for Guiding Questions.

Lab Guiding Questions – Maximum 12 points

- 1. If you need to determine the acceleration of the elevator during an upward trip and a downward trip, how many free-body diagrams do you need to solve this problem? Why? Also, include your free-body diagram(s) below.**
 - Response provides reasoning for the number of free-body diagrams necessary supported by logic. The free-body diagram(s) are included as part of the explanation. **(2)**
 - Adequate logic is presented to support the student's response but no FBD is included. OR proper FBD(s) are included but the supporting logic is not correct or complete. **(1)**
 - Some reasoning and/or a FBD is presented but the approach is incorrect. **(1/2)**
 - No approach or logic is presented. **(0)**
- 2. How did you decide what information needed to be recorded during the lab?**
 - Response includes correct reasoning and is supported by theory and equations. **(2)**
 - Response includes correct reasoning but supporting theory and equations are incomplete or incorrect. **(1)**
 - Some reasoning and/or a FBD is presented but the approach is incorrect.

(1/2)

- No approach or logic is presented. (0)

3. What relationship do you expect to see between the graphs of measured force and acceleration? Explain this relationship using Newton's 2nd Law.

- Response is correct and an explanation of the relationship between the graphs is supported using Newton's 2nd Law. (2)
- Response shows some understanding of Newton's 2nd Law and the relationship between the graphs but the explanation is incomplete or incorrect. (1)
- A conclusion and some supporting reasoning is presented though the response is incorrect. (1/2)
- No approach or logic is presented. (0)

4. Did you see the relationship you expected to see if/when acceleration was measured? Explain.

- Response provides a clear, concise answer and addresses the relationship between the expected result and the experimental result in a thoughtful way. (2)
- Response is clear and concise but doesn't provide an explanation. (1)
- Response is unclear. (1/2)
- No response is presented. (0)

5. Can we use the same equation to calculate the acceleration of the elevator in both the upward and downward direction? If so, show how. If not, what do we need to change?

- Response is correct and an explanation is provided and supported by FBD(s), explanation of theory, and equations. (2)
- Response is correct but explanation is incomplete or incorrect. OR Response is incorrect but appropriate math and logic is presented. (1)
- A conclusion and some supporting reasoning are presented though the response is incorrect. (1/2)
- No approach or logic is presented. (0)

6. If we were to use an object of twice the mass to perform the same experiment, how would you expect the results to change?

- Response is correct and an explanation is provided and supported by FBD(s), explanation of theory, and equations. (2)
- Response is correct but explanation is incomplete or incorrect. OR Response is incorrect but appropriate math and logic is presented. (1)
- A conclusion and some supporting reasoning are presented though the response is incorrect. (1/2)

- No approach or logic is presented. **(0)**

CONCLUSION

Preface to Initial Testing Discussion

This section must be prefaced by saying that initial tests were extremely limited in their scope. Specifically, the initial testing of the lab procedure was performed by the author of the lab procedure and two of the author's colleagues. This fact suggests a certain bias is present within the results of the initial testing as all of the subjects had already been exposed to physics within their engineering education and shared some common interests and abilities. That being said, it should be recognized that this should have little negative affect on the achievement of the objectives of the initial testing which were simply to weed out the grosser omissions and vagaries of the procedure and determine the viability of the proposed experiment.

Results of Initial Tests

The initial testing of the lab showed that the procedure could be performed within a 50 minute lab period using the equipment available in the Physics labs at WPI as prescribed by the constraints. Beyond proving the feasibility of the experiment and the acceptable clarity of the instructions, the initial testing also exposed several areas in which the Pre-Lab and the Guiding Questions could be improved to clarify the expectations of the assignment.

Revisions Suggested by Initial Tests

From the initial tests arose several suggestions for improving the quality of the instructional materials. Some suggestions involved simple errata which were subsequently corrected and which do not warrant discussion here. Other suggestions may provide some valuable insight and will be discussed within this report.

Perhaps one of the more interesting suggestions involved the blank sample spreadsheet which was provided in the Pre-Lab assignment. One person suggested that the spreadsheet should be provided with the appropriate number of rows and columns and by another that students should be able to decide for themselves how many rows and columns they will need to record their data. A valid argument could be made for either point of view. One could argue that providing the expected number of rows and columns could limit the students' exploration of the experimental method. Alternately, providing guidance on data collection may be necessary for some students. I suggest that this point is something that may require further investigation. In the meantime, I believe that the discretion of the instructor should be used while considering the implications of the decision for the success of the instruction method in the particular academic situation.

Some questions were also raised about what calculations needed to be done for a particular portion of the lab. In certain groups of students, it may be helpful to point out some of the expectations as to what information is to be derived from their experimental measurements. In other situations, it may be advisable to have students consider this question themselves as part of the exercise.

Beyond these fundamental suggestions, one evaluator suggested that the lab procedure would be more interesting to him if it could be placed in the context of his own area of interest. In particular, being an electrical engineering major, he expressed interest in the operation of the electronic sensor. This raises an important point. Students are naturally more inclined to enjoy exploration of information when their own interests are addressed. In fact my intention in exploring inquiry-based instruction was to try to explore this fact and to try to find a methodology in which this could be used to the advantage of educators and students alike. In the spirit of this idea, I suggest that all appropriate efforts be made to adapt this method of instruction to the general interests of the particular group of students and to appeal to the interests of the particular students when providing one-on-one and small group instruction during the administering of the lab.

The completed lab procedures and the questionnaires completed by the volunteers during the initial testing are available in Appendix C.

Recommendations for Further Testing

Beyond testing the feasibility and effectiveness of the inquiry-based method as presented within this report, some suggestions could be made as to the aspects of the methodology which could be further explored. As was previously mentioned, the effects of providing varying levels of guidance in areas such as the data table sample in the Pre-Lab would be an interesting and hopefully an informative area of investigation. Also, further testing is needed to determine the effectiveness of the methodology in wider groups of students and beyond the bounds of a limited number of disciplines. Finally, the effect of invoking the interests of individual students and ways by which this may be better accomplished provides a wide field for further exploration.

It is also my belief that as further testing is implemented, the scope of the testing of this particular methodology can be narrowed as the procedure is polished and the difficulties and shortcomings of the inquiry-based method become more clearly defined.

Using Further Testing to Polish the Methodology

The aim of further testing should be to determine the shortcomings of the inquiry-based method and to use the information learned from testing to identify the strengths and weaknesses of the methodology so that future adjustments can be made to capitalize on

the strengths of the methodology and to downplay or circumvent the weaknesses of the proposed method. Testing therefore should be performed as a tool for gathering information on the educational properties of the inquiry-based method rather than as a determination of the success or failure of the methodology or procedure.

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APPENDIX A: INQUIRY-BASED LAB MATERIALS FOR STUDENTS

Pre-Lab Worksheet:

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Using Newton's 2nd Law and Free-Body Diagrams to Determine Acceleration of an Elevator

Pre-lab Exercise: (To be completed prior to lab)

Scenario: We must determine the acceleration of an elevator empirically using experimental data. No accelerometer is available. However, a force plate or scale and the elevator are available.

Materials: Force plate or scale, a mass of a predetermined size, an elevator

1. How could data from a force plate or scale be used to determine acceleration of the elevator?
2. How will acceleration of the elevator affect the apparent weight of a body on a force plate or scale? What effect does acceleration have on apparent weight in this situation?
3. What are the independent variables?
4. What are the dependent variables?
5. What conditions need to be held constant?
6. What controls should be used?
7. Write a procedure that you will use to determine the acceleration of the elevator. This should be a step-by-step procedure that someone else could follow to arrive at similar results.
8. Draw any necessary Free-Body Diagrams and derive any equations you may need to calculate the acceleration of the elevator using the data you collect.
9. Create a spreadsheet wherein you will record the necessary data.

Lab Instructions in Web-Page Format:

Note: This page intentionally left blank.

Using Newton's 2nd Law and Free-Body Diagrams

Preamble

This lab procedure is accompanied by a set of instructions for pre-lab preparations and a set of questions which are aimed at determining the strength of your understanding of the material involved. Since it is assumed that you will be able to follow the lab procedure by reading the instructions, your grade will be based on your ability to communicate the principles involved in this experiment rather than your performance of the lab procedures.

Please note that for the purposes of this lab, the elevator will be simulated by the devices as described in the procedure. From this point forward in the instructions and the guiding questions, the simulated elevator will be referred to as the elevator.

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[Part I](#)

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Overview

The objective of this lab is to demonstrate an understanding of Newton's 2nd Law and the importance of using free-body diagrams in problem solving. This will be achieved by using Newton's 2nd Law and free-body diagrams to find the acceleration of an elevator and exhibiting an understanding of the procedure used to discover this information in your answers to the accompanying questions.

You will need to collect the information you decided was necessary during the lab period. If the pre-lab was completed, you should have a table (or Excel spreadsheet) similar to the following in which to record experimental data during the lab period.

<i>Elevator Direction</i>	<i>Beginning, middle or end of ride.</i>	<i>Mass of object on scale</i>	<i>Force reading (maximum or minimum)</i>	<i>Acceleration of the elevator (measured)</i>	<i>Acceleration of the elevator (calculated)</i>
<i>Up</i>	<i>Beginning</i>				
	<i>Middle</i>				
	<i>End</i>				
<i>Down</i>	<i>Beginning</i>				
	<i>Middle</i>				
	<i>End</i>				

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Part I, Preparation

- You should have drawn some free-body diagrams and derived some equations before coming to lab.
- Now, sketch a prediction for the shape of the graph of the measured force during an elevator ride going up and an elevator ride going down (on your guiding questions sheet).

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[Part II](#)

[Part III](#)

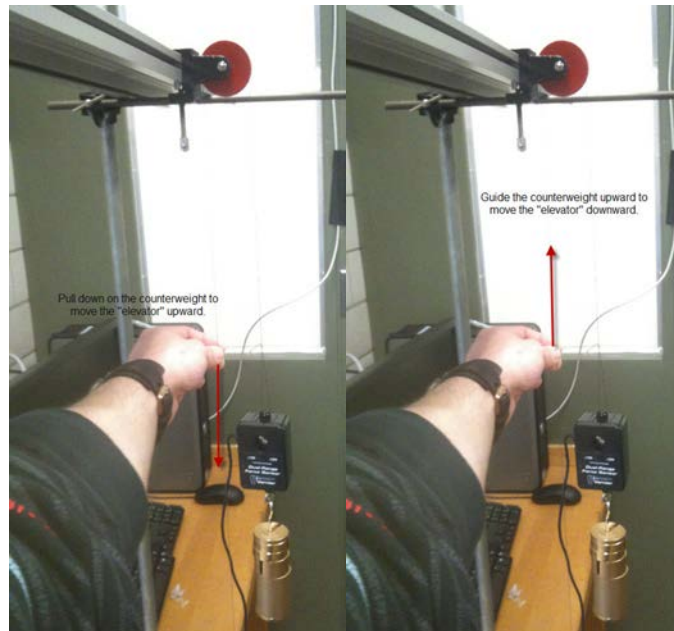
[Worksheet](#)

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Part II, Force Measurements

- Firstly, the switch on the force sensor needs to be set to the ± 50 N setting in order to use a 1kg. hanging mass.
- The sensor must be zeroed in Logger Pro before hanging the mass on the sensor. Once the force value is zeroed you may hang the mass on the sensor and check to see that the force value is close to what you expected.
- Then a trial should be made for the elevator travelling upward. Collect data while simulating an upward moving elevator. In order to simulate an elevator moving upward, students will pull down on the counterweight stopping before the counterweight reaches the floor or the force sensor reaches the pulley. Record the appropriate data in your table.
- Finally collect data for the elevator travelling downward. To simulate a downward moving elevator, students should start with the counterweight near the floor and allow the counterweight to rise in a controlled fashion until the weights hanging from the sensor are near the floor. Record the appropriate data in your table.

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Part III, Calculate Acceleration

- Use the maximum and minimum values of the force data collected during the trials to calculate the acceleration of the elevator. Record the appropriate data in your table.
- Create a graph of the acceleration of the elevator in Logger Pro using the data collected during the experiment.

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Guiding Questions Worksheet:

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FBD Lab Guiding Questions

1. Sketch your prediction for the shape of the graphs of measured force during an elevator ride going up and an elevator ride going down here:

Going Up:	Going Down:
-----------	-------------

2. If you need to determine the acceleration of the elevator during an upward trip and a downward trip, how many free-body diagrams do you need to solve this problem? Why? Also, include your free-body diagram(s) below.
3. How did you decide what information needed to be recorded during the lab?
4. What relationship do you expect to see between the graphs of measured force and acceleration? Explain this relationship using Newton's 2nd Law.
5. Did you see the relationship you expected to see if/when acceleration was measured? Explain.
6. Can we use the same equation to calculate the acceleration of the elevator in both the upward and downward direction? If so, show how. If not, what do we need to change?
7. If we were to use an object of twice the mass to perform the same experiment, how would you expect the results to change?

APPENDIX B: INQUIRY-BASED LAB MATERIALS FOR INSTRUCTORS

Pre-Lab Worksheet with Model Responses:

Note: This page intentionally left blank.

Using Newton's 2nd Law and Free-Body Diagrams to Determine Acceleration of an Elevator.

Pre-lab Exercise: (To be completed prior to lab)

Timeline: 10 minutes of discussion may be needed in class before assigning the pre-lab exercise to explain the format of the lab and the importance of completing the pre-lab before the lab period.

The pre-lab may take students 1-2 hrs. individually.

Scenario: We must determine the acceleration of an elevator empirically using experimental data. No accelerometer is available. However, a force plate or scale and the elevator are available.

Materials: Force plate or scale, a mass of a predetermined size, an elevator

For the instructor: Model responses should be given to students after they have completed their pre-lab exercise and the pre-lab has been assessed (assessment procedure is another area which needs development). It may be helpful to spend some time in conference discussing the pre-lab results before the lab. Students should then have a chance to make revisions to their worksheets before the lab period.

1. How could data from a force plate or scale be used to determine acceleration of the elevator?

Model Response:

From a FBD of an object in the elevator and Newton's 2nd Law, it is apparent that the acceleration of the elevator and the forces acting on the object will be related. (It may be helpful to do this question last.)

2. How will acceleration of the elevator affect the apparent weight of a body on a force plate or scale? What effect does acceleration have on apparent weight in this situation?

Model Response:

When the elevator accelerates upward, the apparent weight should increase. When the elevator accelerates downward, the apparent weight should decrease. The weight of the object should remain constant (near earth's surface). The scale or force plate will be measuring normal force which will be the apparent weight.

3. What are the independent variables?

Model Response:

The acceleration of the elevator, mass of the object (and therefore weight).

4. What are the dependent variables?

Model Response:

Apparent weight or normal force.

5. What conditions need to be held constant?

Model Response:

Mass of the object on the force plate or scale, the particular elevator used, the total occupancy of the elevator (nobody should enter or leave the elevator and the same people should ride the elevator until all data is collected)

6. What controls should be used?

Model Response:

An object of a certain mass. That mass should be: (Possibly determined by the instructor and given in a materials list.)

7. Write a procedure that you will use to determine the acceleration of the elevator. This should be a step-by-step procedure that someone else could follow to arrive at similar results.

Model Response:

- g. Set up the force plate or scale on the floor of the elevator with the mass on top of it.*
 - h. Record the initial reading from the scale or from the force plate.*
 - i. Ride the elevator either up or down and record the changes in the scale reading as well as the direction of travel of the elevator.*
 - j. Ride the elevator the opposite direction and record the same data.*
 - k. Repeat c. and d. and record data for each trial.*
 - l. Calculate the acceleration of the elevator using the data collected.*
8. Create a spreadsheet wherein you will record the necessary data.

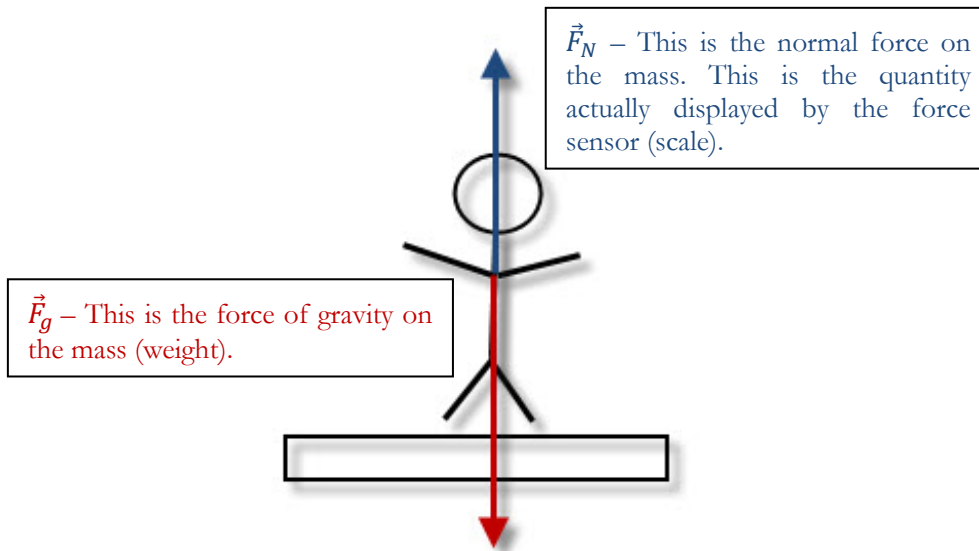
Model Response:

This could be done in excel or by hand.

<i>Elevator Direction</i>	<i>Beginning, middle or end of ride.</i>	<i>Mass of object on scale</i>	<i>Force reading (maximum or minimum)</i>	<i>Acceleration of the elevator (measured)</i>	<i>Acceleration of the elevator (calculated)</i>
<i>Up</i>	<i>Beginning</i>				
	<i>Middle</i>				
	<i>End</i>				
<i>Down</i>	<i>Beginning</i>				

9. Draw any necessary Free-Body Diagrams and derive any equations you may need to calculate the acceleration of the elevator using the data you collect.

Model Response:



Choosing upward as the positive direction

$$\Sigma \vec{F} = m\vec{a} \Rightarrow -\vec{F}_g + \vec{F}_N = m\vec{a} \Rightarrow \vec{a} = \frac{(-\vec{F}_g + \vec{F}_N)}{m}$$

Guiding Questions Worksheet with Model Responses:

Note: This page intentionally left blank.

FBD Lab Guiding Questions

1. Sketch your prediction for the shape of the graphs of measured force during an elevator ride going up and an elevator ride going down here:

Going Up:	Going Down:
-----------	-------------

2. If you need to determine the acceleration of the elevator during an upward trip and a downward trip, how many free-body diagrams do you need to solve this problem? Why? Also, include your free-body diagram(s) below.
Model Response: The problem can be solved with just one free-body diagram. However, a free-body diagram representing the upward moving case and the downward moving case separately may be convenient to simplify some of the arithmetic.
3. How did you decide what information needed to be recorded during the lab?
Model Response: Free-body diagrams should have been drawn and equations should have been set up using Newton's 2nd Law. Once this has been done, it should be clear what needs to be recorded during the lab in order to solve the equations for the acceleration of the elevator.
4. What relationship do you expect to see between the graphs of measured force and acceleration? Explain this relationship using Newton's 2nd Law.
Model Response: The graphs of force and acceleration should have similar shapes because the acceleration of the elevator and the force measured are directly proportional. According to Newton's 2nd Law: $F = ma$. In this case, mass remained constant. So, force and acceleration change proportionally during the elevator ride.

5. Did you see the relationship you expected to see if/when acceleration was measured? Explain.

Model Response: If students had a chance to measure acceleration with an accelerometer or a demonstration was provided using an accelerometer to compare the graphs of acceleration and force, the graphs should have a similar shape exemplifying the proportionality of force and acceleration.

6. Can we use the same equation to calculate the acceleration of the elevator in both the upward and downward direction? If so, show how. If not, what do we need to change?

Model Response: The same equation applies no matter what the direction of the elevator of the elevator is. The direction of travel will be represented by a positive or negative result depending on the free-body diagram and chosen coordinates. Students should include free-body diagrams and equations to make their point. If students made separate FBDs and chose coordinates differently for opposite travel directions, their response is acceptable as long as they explain their reasoning.

7. If we were to use an object of twice the mass to perform the same experiment, how would you expect the results to change?

Model Response: Assuming the acceleration remains the same, we would expect the observed forces to be doubled. We could also speculate that the force the elevator applies is constant. In this case, as long as the students reasoning involving Newton's 2nd Law is correct and their explanation is clear, full credit may be given.

Pre-Lab Worksheet Grading Criteria:

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Assessment Criteria for Inquiry-Based Free-Body Diagram Lab

Pre-Lab – Maximum 18 points

Note: The grading scheme shown in the first example is suggested as a grading scheme throughout.

1. **How could data from a force plate or scale be used to determine acceleration of the elevator?**
 - Theory (Newton's 2nd Law) and Free-Body Diagram accurately represent the situation and the relationship between the forces on the object and the acceleration of the elevator are described. **(2)**
 - Theory and Free-Body Diagram accurately represent the situation. **(1)**
 - A Free-Body diagram is presented. But, the diagram or the theory is incorrect. **(1/2)**
 - No Free-Body diagram or theory is presented **(0)**
2. **How will acceleration of the elevator affect the apparent weight of a body on a force plate or scale? What effect does acceleration have on apparent weight in this situation?**
 - A prediction about the relationship between the apparent weight of the object and the acceleration of the elevator is presented which need not be entirely correct though it should be relevant to the experiment.
 - A prediction is made which is not entirely relevant to the experiment.
 - No Prediction is made.
3. **What are the independent variables?**
 - All relevant independent variables are listed.
 - Some of the relevant independent variables are listed.
 - Some variables are listed. But, they are not the relevant independent variables.
 - No variables are listed.
4. **What are the dependent variables?**
 - All relevant dependent variables are listed.
 - Some of the relevant dependent variables are listed.

- Some variables are listed. But, they are not the relevant dependent variables.
 - No variables are listed.
5. **What conditions need to be held constant?**
- All necessary conditions are described.
 - Some of the necessary conditions are described.
 - Conditions are described. But, they are not relevant.
 - No conditions are described.
6. **What controls should be used?**
- All necessary controls are described.
 - Some of the necessary controls are described.
 - Controls are described. But, they are not relevant.
 - No controls are described.
7. **Write a procedure that you will use to determine the acceleration of the elevator. This should be a step-by-step procedure that someone else could follow to arrive at similar results.**
- The procedure contains step-by-step instructions that could be used to collect the necessary data. The procedure contains no major flaws that would affect the data in such a way that the situation is misrepresented.
 - The procedure contains step-by-step instructions that could be used to collect the necessary data. Some major step is excluded or some misstep is introduced which will cause irrelevant results.
 - A step-by-step procedure is presented. However, it is misguided.
 - No step-by-step procedure is presented.
8. **Create a spreadsheet wherein you will record the necessary data.**
- A spreadsheet has been created which includes space to record all necessary data. The spreadsheet may also include space for calculations and space to record controls.
 - A spreadsheet has been created which includes space for some of the necessary data. But, some important factor is omitted.
 - A spreadsheet is created. But, it does not contain space for any of the relevant data.
 - No spreadsheet is presented.

9. Draw any necessary Free-Body Diagrams and derive any equations you may need to calculate the acceleration of the elevator using the data you collect.

- Appropriate FBDs are presented and derivations of the proper equations are shown from known theories and laws that can be used to accurately calculate the acceleration of the elevator.
- Appropriate FBDs are presented and derivations are shown that incorporate appropriate theories. But, they include algebraic errors. **Or**, the results of derivations are shown correctly. But, the derivation has not been included.
- FBDs are attempted and theories which may be used have been presented or an attempt at derivation has been made. However, the theories or derivations are irrelevant or erroneous.
- No FBDs are included or FBDs are inappropriate and no relevant theory is presented or no attempt is made to derive equations.

Guiding Questions Worksheet Grading Criteria:

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Assessment Criteria for Inquiry-Based Free-Body Diagram Lab

Lab Guiding Questions – Maximum 12 points

1. **If you need to determine the acceleration of the elevator during an upward trip and a downward trip, how many free-body diagrams do you need to solve this problem? Why? Also, include your free-body diagram(s) below.**
 - Response provides reasoning for the number of free-body diagrams necessary supported by logic. The free-body diagram(s) are included as part of the explanation. **(2)**
 - Adequate logic is presented to support the student's response but no FBD is included. OR proper FBD(s) are included but the supporting logic is not correct or complete. **(1)**
 - Some reasoning and/or a FBD is presented but the approach is incorrect. **(1/2)**
 - No approach or logic is presented. **(0)**

2. **How did you decide what information needed to be recorded during the lab?**
 - Response includes correct reasoning and is supported by theory and equations. **(2)**
 - Response includes correct reasoning but supporting theory and equations are incomplete or incorrect. **(1)**
 - Some reasoning and/or a FBD is presented but the approach is incorrect. **(1/2)**
 - No approach or logic is presented. **(0)**

3. **What relationship do you expect to see between the graphs of measured force and acceleration? Explain this relationship using Newton's 2nd Law.**
 - Response is correct and an explanation of the relationship between the graphs is supported using Newton's 2nd Law. **(2)**
 - Response shows some understanding of Newton's 2nd Law and the relationship between the graphs but the explanation is incomplete or incorrect. **(1)**

- A conclusion and some supporting reasoning is presented though the response is incorrect. (1/2)
- No approach or logic is presented. (0)

4. Did you see the relationship you expected to see if/when acceleration was measured? Explain.

- Response provides a clear, concise answer and addresses the relationship between the expected result and the experimental result in a thoughtful way. (2)
- Response is clear and concise but doesn't provide an explanation. (1)
- Response is unclear. (1/2)
- No response is presented. (0)

5. Can we use the same equation to calculate the acceleration of the elevator in both the upward and downward direction? If so, show how. If not, what do we need to change?

- Response is correct and an explanation is provided and supported by FBD(s), explanation of theory, and equations. (2)
- Response is correct but explanation is incomplete or incorrect. OR Response is incorrect but appropriate math and logic is presented. (1)
- A conclusion and some supporting reasoning are presented though the response is incorrect. (1/2)
- No approach or logic is presented. (0)

6. If we were to use an object of twice the mass to perform the same experiment, how would you expect the results to change?

- Response is correct and an explanation is provided and supported by FBD(s), explanation of theory, and equations. (2)
- Response is correct but explanation is incomplete or incorrect. OR Response is incorrect but appropriate math and logic is presented. (1)
- A conclusion and some supporting reasoning are presented though the response is incorrect. (1/2)
- No approach or logic is presented. (0)

APPENDIX C: INITIAL TESTING DOCUMENTATION

First Volunteer:

The assignments completed by the volunteers have been graded using the criteria outlined in this report in order to demonstrate the assessment method.

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James the Electrical Engineer.

Using Newton's 2nd Law and Free-Body Diagrams to Determine Acceleration of an Elevator

Pre-lab Exercise: (To be completed prior to lab)

Scenario: We must determine the acceleration of an elevator empirically using experimental data. No accelerometer is available. However, a force plate or scale and the elevator are available.

Materials: Force plate or scale, a mass of a predetermined size, an elevator

1. How could data from a force plate or scale be used to determine acceleration of the elevator?

$\Sigma F = ma$ You can measure the normal force and then use that to calculate acceleration of the elevator.

1/2

2. How will acceleration of the elevator affect the apparent weight of a body on a force plate or scale? What effect does acceleration have on apparent weight in this situation?

(up) positive acceleration would cause something to be heavier

2

3. What are the independent variables?

mass ; gravity ; F_g

1

4. What are the dependent variables?

F_N ; acceleration

1

5. What conditions need to be held constant?

See independent (3.)

1

6. What controls should be used?

$m = 1 \text{ kg}$ $g = 9.8 \text{ m/s}^2$

2

7. Write a procedure that you will use to determine the acceleration of the elevator. This should be a step-by-step procedure that someone else could follow to arrive at similar results.

Put scale in elevator
put 1kg on scale, tare it.
Then push 50th floor.
Measure the F_N
then plug it in to the formula

$$F_g = F_N = ma$$

↓ ↓ ↓ ↓
known known known find.

known now

1

8. Draw any necessary Free-Body Diagrams and derive any equations you may need to calculate the acceleration of the elevator using the data you collect.



$$F_g - F_N = ma$$

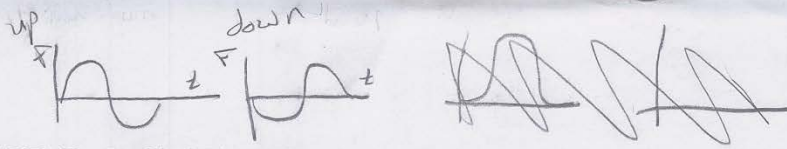
$$F_g = mg$$

1 - Solve for a

9. Create a spreadsheet wherein you will record the necessary data.

	MASS (kg)	F_g (mg)	F_N (mg)	a
Trial 1				
" 2				
" 3				
" 4				

2



FBD Lab Guiding Questions

1. If you need to determine the acceleration of the elevator during an upward trip and a downward trip, how many free-body diagrams do you need to solve this problem? Why? Also, include your free-body diagram(s) below.



1

Because F_N goes negative which accounts for down.

1/2

2. How did you decide what information needed to be recorded during the lab?

Eliminating everything you have everything else will most likely need to be measured.

1

3. What relationship do you expect to see between the graphs of measured force and acceleration? Explain this relationship using Newton's 2nd Law.

They should be the same with force scaled by m .

$F = ma$
 \rightarrow constant at then $F \uparrow$

2

4. Did you see the relationship you expected to see if/when acceleration was measured? Explain why.

Yes the graph is the same.

If not

2

5. Can we use the same equation to calculate the acceleration of the elevator in both the upward and downward direction? If so, show how. If not, what do we need to change?

Yes you can.

$F_N - F_g = ma$
 \rightarrow smaller \rightarrow will be negative

2

6. If we were to use an object of twice the mass to perform the same experiment, how would you expect the results to change?

Just to increase by factor of 2.

2

slow Results?

Note: These units are all correct

Initial Test Survey

How long did the pre-lab take to complete?

5.692×10^{-5} leap years.

How long did the lab take to complete?

2.1×10^{15} pico seconds

How long did it take to answer the guiding questions?

1.2×10^{18} femto seconds

What was not clear (needed further explanation or clearer instruction)?

Which calculations needed to be done. where to show the results.

Would you add anything to the lesson?

Add some electrical stuff. some phasor analysis, how that sensor works.

Would you remove anything from the lesson?

No.

Do you have any other suggestions or comments?

It was good. Definitely a much needed brush up on my physics.

Second Volunteer:

The assignments completed by the volunteers have been graded using the criteria outlined in this report in order to demonstrate the assessment method.

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TIM

Using Newton's 2nd Law and Free-Body Diagrams to Determine Acceleration of an Elevator

Pre-lab Exercise: (To be completed prior to lab)

Scenario: We must determine the acceleration of an elevator empirically using experimental data. No accelerometer is available. However, a force plate or scale and the elevator are available.

Materials: Force plate or scale, a mass of a predetermined size, an elevator

1. How could data from a force plate or scale be used to determine acceleration of the elevator?

$F = ma$
 $a = \frac{F}{m}$
 $m = \text{constant}$
 Data Points
 Measure "a" from that with $1/2$

2. How will acceleration of the elevator affect the apparent weight of a body on a force plate or scale? What effect does acceleration have on apparent weight in this situation?

When the elevator goes up Normal force gets bigger and
 vice versa. 1

3. What are the independent variables?

mass and gravity 1

4. What are the dependent variables?

force and acceleration 1/2

5. What conditions need to be held constant?

the weight 1/2

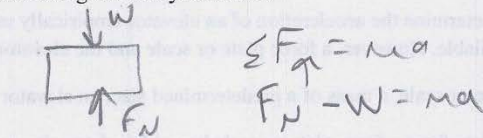
6. What controls should be used?

MASS 2

7. Write a procedure that you will use to determine the acceleration of the elevator. This should be a step-by-step procedure that someone else could follow to arrive at similar results.

scale in elevator. step on. Measure F. Go up in elevator. Measure F while moving. Go down below initial starting point while moving. Measure F. Calculate "a". 2

8. Draw any necessary Free-Body Diagrams and derive any equations you may need to calculate the acceleration of the elevator using the data you collect.

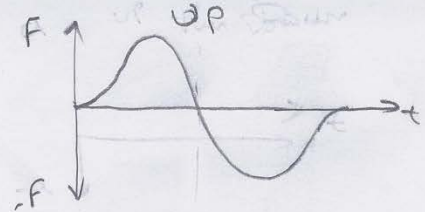


1 - Solve for a

9. Create a spreadsheet wherein you will record the necessary data.

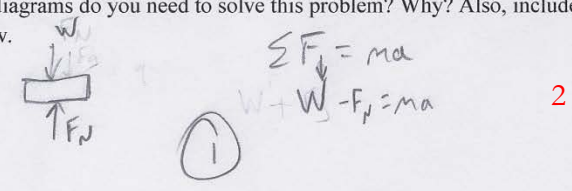
	Run 1	Run 2	Run 3	Run 4
Mass				
Weight				
Force				
Acceleration				

2



FBD Lab Guiding Questions

1. If you need to determine the acceleration of the elevator during an upward trip and a downward trip, how many free-body diagrams do you need to solve this problem? Why? Also, include your free-body diagram(s) below.



2. How did you decide what information needed to be recorded during the lab?

Newton's Second Law $\Sigma F = ma$ 2

3. What relationship do you expect to see between the graphs of measured force and acceleration? Explain this relationship using Newton's 2nd Law.

They will be a factor of m .
 $F = ma$ $a = \frac{F}{m}$ 2

4. Did you see the relationship you expected to see if/when acceleration was measured? Explain.

Yes. The graph is the same. 2

5. Can we use the same equation to calculate the acceleration of the elevator in both the upward and downward direction? If so, show how. If not, what do we need to change?

Yes $F_N - F_g = ma$ 2

6. If we were to use an object of twice the mass to perform the same experiment, how would you expect the results to change?

Double 2

Initial Test Survey

How long did the pre-lab take to complete?

0.001488095 fortnights

How long did the lab take to complete?

8.32382×10^{-6} octennials

How long did it take to answer the guiding questions?

1.2×10^9 microseconds

What was not clear (needed further explanation or clearer instruction)?

↳ Matt wrote notes down.

Would you add anything to the lesson?

It would be cool to do this with a simple scale and an elevator.

Would you remove anything from the lesson?

No it is all pretty important.

Do you have any other suggestions or comments?

Na