Assessment

- Students can be assessed on their inquiry skills using Assessment Rubric 2: Inquiry (Teacher's Resource).
- Students can be assessed on their communication skills if a lab report is required using Assessment Rubric 3: Communication (Teacher's Resource).
- Students can also be assessed on their knowledge and understanding of dynamic equilibrium.

Student Preparation

- Students should be familiar with the concept of static equilibrium, and they should be able to solve problems using the components of forces.
- Teachers can direct students to the text reference to this activity on page 80 and ask students to predict the value of the unknown force ($\vec{F}_2$) before performing this activity.

Pre-lab Discussions

- Students must have a clear understanding of the conditions for static equilibrium and the ability to analyze dynamic situations using the components of forces.
- Teachers may want to provide examples where the components of forces are used to solve problems. For example, components are used in Sample Problem 3 on page 79 to analyze the traction system for a broken leg. Students can also consider suspended traffic lights, suspension bridges, and spider webs.

During the Lab

- Teachers must monitor student progress throughout the lab. Teachers may want to ask groups what directions they have chosen as the reference directions and why. Student groups should be prepared to defend their choices of reference directions. Although this choice is somewhat arbitrary, are some directions better to choose than others?
- Teachers can ask students how they will determine the components of the forces.

Post-lab Discussions

- Teachers may want to lead a discussion of the analysis of a hypothetical arrangement of masses. A full analysis can serve as a model for the students when they are considering their results.
- Discuss systematic and random errors, and how these errors can be minimized.
- Students may want to refer to Appendix A2 on page 764, and Appendix A5 on page 768.

Extensions/Modifications

- As an extension, students can be asked to predict where a third mass or pulley, or both, should be placed given the masses of the other two as in part (b) of the procedure. They can test their prediction on the force board.

Investigation 2.4.1 Measuring Coefficients of Friction

- This activity is a self-directed investigation of static and kinetic friction. Students design and carry out an experimental procedure to determine the coefficients of static and kinetic friction between two surfaces.

BACKGROUND INFORMATION

In the introduction to this investigation, students are directed to Sample Problem 2 on page 100. In this problem, it is apparent that the coefficient of static friction is equivalent to the tangent of the angle of inclination of the ramp. The determination of the coefficient of kinetic friction is left to the students. The key is to have the objects sliding along the ramp at a constant speed so that

the component of the gravitational force down the ramp is just balanced by the kinetic friction acting up the ramp. Students must determine how they can ensure that objects are sliding at a constant speed. There are a variety of ways to do this. Teachers should encourage students to keep their procedures simple.

Related Background Resources

- *Nelson Physics 11*, Section 3.3, page 96
- *Nelson Physics 12*, Section 2.4, pages 97–106
- *Nelson Physics 12*, Sample Problem 2, page 100

Teacher Preparation

Time: 10 min

Instructional Resources

- Textbook Investigation 2.4.1
- Lab and Study Master: Student Worksheet LSM 2.4-1 Investigation 2.4.1 Measuring Coefficients of Friction
- Solutions Manual
- Appendix A2: Planning an Investigation
- Appendix A5: Lab Reports

Material/Equipment	Quantity per station	Quantity for 16 stations
ramp (see below)	1	16
objects for sliding (see below)	1 or more	16 or more

Materials and Equipment Notes

- A variety of materials can be used as ramps for this investigation. Several metre sticks taped together provide a wide surface that can be covered with different materials, such as paper, plastic, and fabric.
- A variety of objects found in the classroom, such as calculators, a chalk brush, an eraser, or a textbook, can be used to slide down the ramp.
- Teachers may want to leave the choice of materials to the students, or keep one of the contact surfaces the same for all groups and test the effect of changing the other surface on the relative coefficient of friction. For example, all groups can use the same ramp materials and slide different objects along the ramps.
- The supply of materials should not be an issue in this investigation. It is suggested that the group size be kept to 2 or 3.

Safety and Disposal

- Teachers should check and approve students' choices of equipment before the students begin their investigation.

Assessment

- This self-directed investigation presents an opportunity to assess inquiry and communication skills. Students' abilities to design, carry out, and modify an experimental procedure, as well as communicate their findings in a report, can be assessed using Assessment Rubric 2: Inquiry (Teacher's Resource), and Assessment Rubric 3: Communication (Teacher's Resource).
- Students' knowledge and understanding of the concepts of static and kinetic friction can also be assessed using Assessment Rubric 1: Knowledge/Understanding (Teacher's Resource).

Student Preparation

- Students should be directed to Sample Problem 2 on page 100 as an introduction to this investigation.
- Groups should be directed to read the investigation on page 113 and prepare an appropriate experimental procedure. How groups collect and record their data can also be determined before class.
- Students should understand how they will analyze their experimental data and draw conclusions based on the experimental evidence.

Pre-lab Discussions

- It is imperative that students understand what to measure and how to make those measurements before attempting the investigation. Discuss how students will ensure that the objects slide at a constant speed when determining the coefficient of kinetic friction.
- A discussion of experimental controls and the necessity of identifying systematic and random errors is suggested.

During the Lab

- Teachers should monitor the students' progress throughout the investigation and ensure that the procedure is being carried out in a safe manner.
- Ask students about experimental controls and the determination of scientific errors while the experiment is in progress.
- Teachers should ask students how they can modify their experimental procedure or suggest appropriate modifications while the investigation is in progress.

Post-lab Discussions

- A class discussion on the results of the investigation is useful and can involve comparing values among groups who used the same materials. Have students explain any discrepancies.
- Students will benefit from a class discussion of sources of experimental errors and how the procedure can be modified to minimize such errors.
- Students may want to refer to Appendix A2 on page 764, and Appendix A5 on page 768.

Extensions/Modifications

- The coefficient of kinetic friction can be determined in a similar procedure when the object accelerates down the ramp, provided the acceleration can be determined. The kinetic friction is the difference between the net force (the product of the mass and the acceleration) and the component of gravity along the ramp.
- In a more elaborate version of this investigation, motion sensors can be used at the top of the ramps to determine the speed or acceleration of the sliding objects.