UDL Teacher Guide: Intermediate Friction

Friction in Everyday Life

Amontons' laws of friction (1699)
(1) Friction is independent of the apparent area of contact
(2) The frictional force F is directly proportional to the normal load W

Driving Question: What if there were no friction?

This unit explores how friction affects how things move.

Introduction

Using the UDL approach, students actively explore the movement of materials in their world. Friction is one of the forces that affects how things move. Students will learn about friction in multiple ways: from a fictional story to data collection with probes, and from hands-on inquiry investigations to using computer models.

Technology

The technology used in the friction unit is designed to allow students to discover the story told by the data they collect as they investigate friction. A force sensor is used in "Dragging Shoes" to gather data about the amount of force required to move over different surfaces.

Smart graphs allow students to analyze data in a meaningful and supported way. The graphing tools are the same regardless of the activity.

The technology in UDL does not supplant the teacher. Instead, students are individually supported throughout the unit. One example of this support is that students can highlight the text and the computer will vocalize the words. Definitions for highlighted words (in blue) are also built into the program. A complete glossary for the unit can be found at the bottom each page using the book icon. In some of the units you will also find three robot helpers. These robots help the student understand the material by asking them to make predictions, asking guided questions, and by clarifying or predicting what will happen next.

The teacher can manage certain features of the units for both the class and individual students. Once a class is set up the teacher can go to the UDL Portal-Info page and click on the "View a report on this class" icon. At the top of the report page there are two options, one that allows you to configure the parameters for students. This allows you to control the font size and set the initial scaffolding level for students. The option on the class report page allows you to enable/disable activities within the units.

The default setting for lesson order when setting up your classes will be a sequenced order of lessons. When students enter the menu page they will complete the Pre-test. When they have submitted the Pre-test they will be able to access the next lesson in the sequence. If you want to allow students to choose their own sequence you can set up your class so that once they have completed the Pre-test and Introduction they can move between lessons in whatever order they like. (A more detailed explanation can be found at http://udl.concord.org/share/teacher-guides/Dashboard.pdf)

Scaffolding in UDL Units

Scaffolding in education has traditionally been done by the teacher as a way to assist students as they are learning new skills or content. The scaffolding is done not to provide answers or do the work for them but as a way for the students to gain confidence and develop understanding of skills and concepts. The goal of scaffolding is that over time the level of assistance that a student needs will gradually be reduced until the minimal amount of support is needed and used. To use a cooking analogy: a chef will use a recipe the first few times he makes a dish. After he has made it several times, he may have the recipe out for reference and then after more time, it becomes so natural he no longer needs the recipe.

In the UDL units different levels of support are offered to students when answering questions. As with the cooking analogy, the scaffolding is intended to provide support for those students who need it with the goal that with time they will be able to work with minimal scaffolding. When scaffolding prompts are available they are accessed by clicking on the green question mark icon. Students may answer the open-ended question as presented. Or, if they are unable to do so, they can click on the question mark and access the first level of support. At this level they are given a hint that may lead them to the correct response. If the student is still unable to answer the question, they can click the question mark again for the answer with key words left out and they can fill in the blanks. If they need additional help, they receive a multiple-choice list. The final level of scaffolding offers the student a model response; they are given the answer and asked to provide their own ideas about the response.

Standards/Benchmarks

NSES Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry.
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    - Design and conduct a scientific investigation.
    - Use appropriate tools and techniques to gather, analyze, and interpret data.
    - Develop descriptions, explanations, predictions, and models using evidence.
    - Think critically and logically to make the relationships between evidence and explanations.
- Understandings about scientific inquiry.
    - Mathematics is important in all aspects of scientific inquiry.
    - Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.

NSES Content Standard B: Physical Science (5-8)

- Motions and Forces
    - The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph.
- Transfer of Energy
    - Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.

Benchmarks for Science Literacy—AAAS

- 1B Scientific Inquiry
    - Scientific investigations may take many different forms, including observing what things are like or what is happening somewhere, collecting specimens for

analysis, and doing experiments. Investigations can focus on physical, biological, and social questions.
    - Scientists do not pay much attention to claims about something they know about works unless the claims are backed up with evidence that can be confirmed and with logical argument.
- 4E Energy Transformation
    - Energy cannot be created or destroyed, but only changed from one form to another.
- 4F Motion
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Learning Goals

Friction is a sticky force between surfaces that slows things down or keeps them from sliding.

Different materials have more or less friction.

If there were no friction, things would keep going for ever.

Friction happens because atoms on the two surfaces stick to each other. It takes energy to break them apart and make the object slide.

Friction changes energy of motion into heat energy and surfaces get hotter.

- When there is more friction, the surfaces heat up more.
- When there is less friction, the surfaces heat up less.

Background Information

Scientific inquiry is a marriage between evidence and reason, careful observation, and use of evidence to support scientific ideas (Atlas for Science Literacy, AAAS, vol.1). Scientific thought changes as new evidence is presented. Friction is one of the commonly identified forces when talking about motion, but is little understood by students at the elementary level. All students have experienced the force of friction, whether on the slide on the playground, the climbing rope in the gym, or the newly waxed floor in the hallway. Friction is the force that causes the motion between two objects to be reduced.

Leonardo Da Vinci (1452-1519) was one of the first scholar-scientists to study friction. In his work on designing and building machines he recognized the impact of friction in the effectiveness of his machines. He identified two kinds of friction, sliding friction and rolling friction. Da Vinci defined two basic laws of friction:

1. The areas in contact have no effect on friction.
2. If the load of an object is doubled, its friction will also be doubled.

Based on his observations of different materials moving, he noted that they moved with different ease. He believed correctly that this was the result of the roughness of different materials. While he never published his ideas, evidence of them is found in his journals.

Later Guillaume Amontons (1663-1705) worked to discover how friction works. He rediscovered the two laws that Da Vinci had discovered and over the course of his career developed other original theories about friction. His ideas focused on the roughness of surfaces. He thought that friction was mostly the result of the work to lift one surface over the roughness of another, or from deforming of the other surface.

Charles August Coulomb (1736-1806) added to the second law of friction the idea that "strength due to friction is proportional to compressive forces, … although for large bodies friction does not follow exactly this law." In his writing Coulomb referred to Amontons' work leading to the second law of friction to be referred to as "Amontons-Coulomb Law."

The study of friction has continued into present times with F. Philip Bowden and David Tabor (1950) giving a physical explanation for the laws of friction. They were able to determine that the true area of contact is a very small percentage of the apparent contact area. There are asperities (microscopic rough areas) on all surfaces even the smoothest of polished glass. These form the contact points for surfaces. As normal force increases, more asperities come into contact. Research today continues focusing on the micro scale to help better understand friction as a force.

There are three broad types of friction: sliding friction, rolling friction, and fluid friction. Sliding friction results when two solid objects are in contact and a force is applied to one object causing it to slide across the other. Sliding friction force resists the motion. Sliding friction is caused by adhesion between materials, the roughness of surfaces, and in soft materials by deforming of the material.

Rolling friction is a resistive force that slows an object that is rolling. For example, a wheel will start rolling if a force is exerted on it; once it is rolling, rolling friction will take over. This is mostly caused by adhesion between surfaces. The causes of rolling friction are much the same as those that cause sliding friction: adhesion of materials, surface roughness, and material deformation.

Fluid friction occurs when a solid object is in contact with a fluid and a force is applied. There will be friction that resists the motion. When a boat is moving through water or a plane is flying through air, the movement of the fluid (water or air) will cause resistance. The causes of fluid friction are disruptive effects from surface roughness and deformities, adhesion between materials, and deformation resistance of the fluid.

Unit Overview

Activity Title	Activity Length	Materials	Overview
Pre-test	20 minutes	▪ computer with Internet access	A short pre-test allows students to preview unit concepts and demonstrate prior knowledge.
Introduction	15 minutes	▪ computer with Internet access	Students begin to explore the question, "What does friction do?" Responding to a series of prompts students

			share their ideas about friction and the heat that friction can produce.
Frictional Adventure	Two-three 30-minute sessions	▪ computer with Internet access ▪ printout of story (http://udl.concord.org/share/teacher-guides/FrictionalAdventure56_v4.pdf)	Students read "Martin and Emily's Wonderful Summer: A Frictional Adventure," which tells the story of their visits to Sticky and Slippery Worlds. Students respond to questions at the end of Chapters 1, 3, 4, 8 and 9.
Penny Warming	45-60 minutes	▪ surface temperature probe (fast response) ▪ computer with Internet access ▪ 4 pennies ▪ wood block (optional) ▪ tape ▪ piece of cardboard (2 cm x 4 cm) ▪ waxed paper (or rub wax on a surface with a crayon)	Students investigate how much a penny heats up when it is rubbed on a surface. The surface temperature probe is used to measure and graph temperature changes in a smart graph.
Hot Stuff	30 minutes	▪ computer with Internet access	Students use a molecular model to explore how friction creates heat. They are able to look at the surface interface and see what it would look like at the molecular level.
Start Moving	Two 40-minute sessions	▪ force sensor ▪ cardboard box just large enough to hold two .5-liter water bottles ▪ two .5-liter water bottles filled with water ▪ sandpaper ▪ paper clips ▪ computer with Internet access	Students investigate how the soles of different shoes affect how much friction they produce.
Halt!	30-40 minutes	▪ computer with Internet access	Students explore changing kinetic energy and heat energy for a sliding object using a computer model.
Measuring Challenge	30-40 minutes	▪ computer with Internet access	Students analyze data from friction experiments using a measure of central tendency (average). They are also introduced to the concept of outliers in a data set.
Wrapping Up	Ongoing	▪ computer with Internet access	Students can visit and revisit "Wrapping Up" during their completion of the unit activities. In Wrapping Up they have the opportunity to

			review and clarify their thinking.
Post-test	20 minutes	▪ computer with Internet access	Students complete the post-test, which contains the same set of question as the pre-test, as well as student feedback questions.

Unit Activities

Pre-test

Time: 20 minutes

Materials: computer with Internet access

This unit begins with a short pre-test. The pre-test allows students to share what they already know about the learning goals. Students must complete the pre-test and press the “Submit” button before proceeding to any of the activities. The post-test at the end of the unit contains the same set of questions. Based on student responses to the multiple-choice questions, teachers will be able to make recommendations about which activities each student should complete.

Introduction

Time: 15 minutes

Materials: computer with Internet access

The driving question “What does friction do?” is introduced. Students answer questions about different surfaces and the force of friction. They also begin to identify that heat may result from frictional forces. This unit explores how different surfaces affect how objects move across each other. As students work through the unit it is important to come back to the driving question to help students focus on the force called friction. Posting this question in the classroom is one way to help reinforce the question.

Frictional Adventure *Story*

Time: Two or three 30-minute sessions

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Materials: computer access (or you can print a PDF version)

Student Activity:
Martin and Emily are on summer vacation and are complaining to their mother about not having anything to do. Their mother tells them that they are going to visit two old friends, Albert who lives in "Sticky World" and Jennifer who lives in "Slippery World." Along the way Martin and

Emily learn some things about friction. Students respond to questions at the end of Chapters 1, 3, 4, 8 and 9.

Scaffolding is available using the “robot” helpers, which provide prompts to help students understand the story.

Teacher Notes:

Friction is a force that all children have experienced; they may have already developed some ideas about how friction works. They may also have developed some misconceptions, such as:

- Friction always hinders motion. Thus, you always want to eliminate friction.
- Friction is the same thing as reaction.
- Friction depends on movement.
- Friction is always associated with energy, especially heat.
- Friction occurs only between solids.
- Friction occurs with liquids, but not with gases.
- Friction causes electricity.

Being aware of these misconceptions and listening to student conversations is important in helping to address misconceptions and develop accurate understandings.

Penny Warming — *Hands-on (temperature sensor)*

Discovery Question: How can you get the most warming from friction?

In this activity students measure how much a penny heats up when it is rubbed on a surface.

Time: 45-60 minutes

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Advanced Preparation: This activity requires you to collect and cut cardboard.

Materials:

- cardboard (2 cm x 4 cm)
- wood block (optional)
- 4 pennies
- waxed paper
- surface temperature sensor (fast response)
- tape
- computer with Internet access

Student Activity:

Engage:
Students begin by rubbing their hands together and noting that heat is produced. They are asked to think about why this happens and write their ideas. They then rub a penny on a hard surface and make a qualitative measure of heat.

Explore:
Students start with a practice exercise reading and analyzing a graph. They are given a graph that shows penny heat data; they mark and identify various stages of the data. As they work through the practice exercise they can check their answers.

Then, using a piece of cardboard, tape, surface temperature sensor, and a penny, they construct the heat testing system. They use the cardboard as an insulator. They collect data that is also graphed.

Teacher Notes:
Monitor students to make sure that they have the end of the sensor between the penny and the cardboard. Students should be instructed that they don't have to press hard, as this may cause the sensor to break.

Explain:
Students now identify various places on their graph – including when they rubbed slowly and when they started rubbing fast. They answer questions that help them analyze the data. They take a snapshot of their graph for their lab book.

Elaborate:
Students are asked to think about how they can cause the temperature to increase with friction. Then they apply what they have discovered to the braking system on a car and the heat of friction produced.

Discussion:
Lead the whole class in a discussion using the questions below to start the conversation. Allow students time to clarify their ideas and encourage them to explain their thinking.

"Explain where the energy is coming from that causes the penny to heat up."

"Are there ways that we use the heat created by friction?"

Hot Stuff *Computer model*

Discovery Question: Why does a surface heat up when you rub it against another surface?

In this activity students explore a molecular model to see how friction creates heat. Students analyze the data from the model.

Time: 30 minutes

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Materials: computer with Internet access

Student Activity:

Engage:
Students begin by rubbing their hands together to produce heat. They then view a box on a slide and enlarge the interface between the two surfaces. As they zoom in they can see that surfaces, even seemingly very smooth ones, are rough close up.

Explore:
Students use the molecular model to explore how heating and cooling a solid changes the way atoms move. They take two snapshots and annotate views of the model for their lab books. Students observe an animation of a box moving across a rough surface. They see the change in temperature on a temperature bar, as well as in the movement of molecules in the model.

Explain:
Having observed and recorded the data from the tests, students use this information to develop an explanation of what they observe. They think about why rough surfaces with lots of friction

produce more heat and surfaces with less friction produce less heat. They are asked to use the words atoms, temperature, and surface in their explanation.

Elaborate:
Based on their observations students are asked to think about what is done to reduce friction. One example is the use of oil in a car engine.

Start Moving ***Hands-on (force sensor)***

Discovery Question: How strong is the force of friction?

In this activity students measure the amount of force needed to make a box start to move and continue to move.

Time: Two 40-minute sessions

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Advanced Preparation:

Before starting this lesson, collect 10-15 small (about 500 ml or 16 ounce) bottles. Fill these with equal amounts of water to use as masses. Also locate 6-8 small cardboard boxes large enough to hold 2 bottles (about 6 in. x 3 in. x 2 in.).

Materials:

- computer with Internet access
- force sensor and connection cable for computer
- 500 ml (16 oz.) plastic bottles filled with water
- box large enough to hold 2 bottles
- paper clips
- sandpaper (8" x 10")

Student Activity:

Engage:
The activity starts with a short introduction where students begin thinking about the force needed to move different objects. Students list things that would take a big push or pull to move and things that would need a small push or pull. They then use the box/water bottle system to collect qualitative data.

Explore:
Students start by doing a practice exercise that shows data collected by pulling a box with bottles of water in them. Students label various locations on the "smart graph" and can check their responses as they practice.

Having had the chance to practice reading and analyzing the graph, students now use the force sensor, box, and bottles to graph the force when one bottle is added to the box. They can do multiple trials, but should take at least one snapshot of the trials to add to their lab book.

Explain:
Students now think about variables that would change the amount of frictional force. They are asked to think of two things that would increase the force and two that would decrease the force.

Elaborate:
Students add a second bottle and repeat their test. They then analyze the data and find the ratio of the force required for one and two bottles. Having looked at the data, students then answer several questions about the relationship between weight and the force of friction. They are also asked to describe what it would look like where the two surfaces meet and whether pushing and pulling would produce similar results.

Discussion:
Lead the whole class in a discussion using the questions below to start the conversation. Allow students time to clarify their ideas and encourage them to explain their thinking.

"What can you do to reduce the friction between two objects?"

"Think about where the box and table meet, and describe what you could do to decrease the friction?"

Halt! *Computer model*

Discovery Question: When an object slows down, where does the energy go?

In this activity students observe the changing kinetic energy and heat energy for a sliding object.

Time: 30-40 minutes

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Materials: computer with Internet access

Student Activity:

Engage:
Students begin by thinking about a girl sliding into home plate and where the energy goes when she comes to a halt. Then they are shown smoke coming from wheels of a landing plane and are asked what is producing the heat.

Explore:
Using the computer model, students run a simulation of a box moving across different surface materials. As the box is pushed the energy is graphed over time. The kinetic energy is graphed as is the heat energy of friction. A third line shows the sum of the two. Students take a snapshot of their model for their lab book. The first surface they test is steel, and then they run the model with wood as the surface.

Explain:
Students are asked to use the information they gathered to explain why the heat energy goes up when the kinetic energy goes down.

Elaborate:
Having looked at data from wood and steel, students then run the model with a surface that has more friction (carpet); they analyze the difference between the graphs created by the various surfaces. A snapshot of their data is added to lab book. Students now think about what they have observed and how it relates to energy in an isolated system.

Measuring Challenge — *Math*

Discovery Question: If a series of measurements vary, how do you decide on the best value?

In this activity students analyze data from friction experiments. A measure of central tendency (average) is used to explore how to determine the best value to use. Students are also introduced to the concept of outliers in a data set.

Time: 30-40 minutes

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  - Energy cannot be created or destroyed, but only changed from one form to another.
- 4F Motion
  - Something that is moving may move steadily or change its direction. The greater the force is, the greater the change in motion will be. The more massive an object is the less effect a given force will have.

Alaska state standards (http://udl.concord.org/share/teacher-guides/TG_Friction-Intermediate-AK-Standards.pdf)

California state standards (http://udl.concord.org/share/teacher-guides/TG_Friction-Intermediate-CA-Standards.pdf)

Materials: computer with Internet access

Student Activity:

Engage:
Students are given a set of weights that were measured of the same object. They are asked how they would decide on what the weight of the object really is. This leads to the idea of finding the mean of a data set.

Explore:
Students use a data table from an investigation of how high a ramp must be raised before a shoe starts to move on different surfaces. They use the data to find the mean (average) for each surface.

Explain:
Students are asked to explain why there are variations in the data for the different materials and what could be done to get more accurate results.

Elaborate:
Students are introduced to the idea of outliers in a data set and how they could deal with these outliers. Then they are shown five ways to get more accurate measurements and to chose one and explain why it's a good idea.

Wrapping Up

Discovery Question: What does friction do?

Students use their drawings, text responses, snapshots of models, and probe data in their lab books to answer the question "What does friction do?"

Time: Ongoing

Note: Students may want to work on the "Wrapping Up" as they are working on the unit. They can come back to this section as frequently as they would like while they complete the unit. If they have been adding to the "Wrapping Up," they should review and refine their thinking before accessing the post-test.

Materials: computer with Internet access

Student Activity:
Students use their lab book to review and think about the activities they have completed in this unit. Students can work on the "Wrapping Up" section throughout the unit.

When students are finished, they should let the teacher know so that they can get the password to access the post-test.

The password is: **friction**

Post-test

Time: 20 minutes

Materials: computer with Internet access

In the post-test, students have an opportunity to rethink their answers to the same set of questions as the pre-test. Once students open the post-test, they will not be able to return to previous activities.

Note: When students finish the post-test, a box comes up saying they have finished and should tell the teacher. At that moment, their data is *not yet saved*. They must close the unit for the data to be saved. Students cannot just walk away from the computer. They can close the unit by going to the File menu and selecting Exit, or simply clicking the red circle (upper left) to close it.

Additional Resources

Vocabulary

Analogy: a comparison between two situations or things that are alike in some ways, but different in others.

Atom: a very small piece of matter. Several atoms joined together are called molecules.

Average: the middle of a set of values. To calculate it, add up the values and divide by how many there are.

Computer model: a program that runs on a computer and imitates the real world in some way.

Cycle: something that repeats over and over again, like traveling around in a circle or swinging back and forth.

Energy: a property of materials that can be used to heat things. It can take many forms, such as motion, electrical or chemical energy. The total amount of energy in a system doesn't change.

Estimate: to make a careful guess of the numerical value of something.

Evidence: what you observe or measure to support an idea.

Force: a push or pull that tends to make an object move, stop, or change direction.

Friction: a force that resists the motion of objects.

Grid: a square pattern of lines.

Heat: a form of energy that consists of the movement of molecules. The faster the molecules wiggle, the hotter the material.

Kinetic energy: the energy of motion. If an object is not moving, its kinetic energy is zero.

Molecule: a group of atoms that are joined together.

Newtons: unit of force. A force of one Newton will accelerate a mass of one kilogram at the rate of one meter per second per second.

Outlier: in a collection of measurements, an outlier is one that is very different from the others.

Potential energy: stored-up energy, such as a stretched rubber band, chemical energy in a battery, or a car at the top of a hill.

Predict: to make a careful guess about how something will happen.

Sliding: moving smoothly over a surface.

Surface: the outside of an object or body.

Temperature: the measure of how fast molecules in a material are wiggling or vibrating.

