

SECTION 2.3 INTRODUCTION

2.3 Redesign Your Investigation

1 class period* ►

Getting to a Better Procedure

Overview

Students identify factors in their investigation that lead to inconsistent results, and then design a more precise class procedure to control these factors. They design a class procedure that is detailed and replicable, controlling each factor they identified. Finally, students reflect on their new procedure by comparing it to the different original procedures to see how their ability to plan an investigation has improved.

Targeted Concepts, Skills, and Nature of Science	Performance Expectations
Identifying factors that lead to variation is an important part of scientific investigations.	Students identify factors that can affect the results of an investigation.
Scientific investigations and measurements are considered reliable if the results are repeatable by other scientists using the same procedures.	Students describe how investigations and measurements are considered reliable if they can be repeated by following the same procedures. Supporting reasons should include observations from the previous section, such as that when groups used different results, they all came up with different answers and they couldn't decide which answer was correct.
Scientists often work together and then share their findings. Sharing findings makes new information available and helps scientists refine their ideas and build on others' ideas. When another person's or group's idea is used, credit needs to be given.	Students consult their peers in planning, and they share their results with their peers.

*A class period is considered to be one 40 to 50 minute class.

Materials

- | | |
|-------------|---|
| 1 per class | media for creating class procedures (e.g., butcher block paper, overhead) |
| 1 per class | class list of criteria and constraints |

Homework Options**Reflection**

- **Science Content:** Scientists in City A spent two hours one evening catching fish in a stream using an experimental new bait and caught five fish, while scientists in City B spent three hours one morning catching fish in a lake using the same bait and caught two fish. They could not reach any conclusion about how many fish an angler can catch using the bait. What are the factors that led to the different results? What are some practical ways the scientists could reduce the variation? (*Check to see if the answer addresses the differences between the studies: in this case, a difference in settings—stream vs. lake—and a difference in time.*)
- **Science Process:** Think about the criteria and constraints you listed for your first investigation with the plate and dish soap. Identify some additional criteria and constraints that will guide your next investigation with the plates and dish soap. (*Answers may include: criteria—a set of procedures that everyone can follow; constraints—number of trials.*)
- **Nature of Science:** Describe the reasons for creating a clear, standard procedure. (*Answers should point out the need for other researchers to be able to run the same procedure and get similar results. Otherwise the results are not considered reliable.*)

Preparation for 2.4

- **Science Content:** If everyone in class follows the class procedure, what do you expect the line plot of the results will look like? Draw a picture to illustrate your answer. (*Answers should say something about the data being more clustered. The picture should depict a line plot with tightly clustered data.*)

1 class period ►

2.3 Redesign Your Investigation

Getting to a Better Procedure

15 min.

Have students design a standard class procedure to get a smaller distribution of data.

SECTION 2.3 IMPLEMENTATION

2.3 Redesign Your Investigation

Getting to a Better Procedure

repeatable: when someone follows the reported procedure, they get similar results.

replicate: to run a procedure again and get the same results.

Your class probably did not agree on how fast the lava flows. Your line plot may have shown that your class cannot produce reliable results. You will now see if you can find a way to make the results more consistent across groups.

Think about what went wrong. You were all trying to answer the same question. You all measured the flow of dish soap across a plastic plate. You all used the same unit of measurement. You all had the same materials. But every group used a slightly different procedure. You all collected data in different ways. No wonder the results were so varied.

Designing Good Procedures

Scientists only trust experimental results that are **repeatable** by other scientists. In order for other scientists to **replicate** the results of an investigation, the procedures must be reported very precisely. Then someone else can run the procedure again and get the same results.



Making Procedures Repeatable

For example, suppose you wanted to investigate the effect of a fertilizer on the growth of plants. You would need to keep many other factors the same:

- soil type,
- time spent in sunlight each day,
- amount of water, and
- type of plant.

Think about one factor, water. You would need to make sure that each group of plants got the same amount of water. They would need to be watered the same number

Project-Based Inquiry Science

DIG 34

Engage

Now that students have seen evidence of their inconsistent data by using the line plot, and have thought about why their results were inconsistent, ask them if they can design a procedure that would get them better results. Display the class graph during this discussion.

TEACHER TALK

“Look at our class graph again. There are a lot of different results. You’ve thought about what made your results different. Why do you think the results are so varied? Scientists are interested in procedures that can be repeated by others and provide consistent data. What can you do to make a procedure that would help your class results be less varied?”

△ Guide

Begin by reminding students of the differences in procedures and materials they identified and some of students' ideas for getting more reliable results.

Then lead the class in identifying all the things they will need to pay attention to when revising their procedure.

TEACHER TALK

“Let’s think about all the factors that need to be the same from trial to trial—things we need to think about in our new procedure.

What are some of the things you did differently from other groups? What are some of the things you should have done the same?”

As students identify factors in their investigations and ways their procedures were not standardized, record the factors so that students can reference this list when the class creates a standard procedure in the next step.

Many of the factors identified should involve inconsistencies with measurement. Discuss how they should all use the same measurement. Emphasize that a standard procedure will need to describe how each of these factors will be measured and controlled.

By this time, students should begin to see that the tilt of the plate changes the speed of the flow. This is one very important variable. If students haven't discussed this, remind them that how much they tilt the plate affects how much time the dish soap takes to cross the plate.

The volume of the dish soap will also affect how fast it flows. Have the class agree on an amount of lava to put on the plate and how they will measure it. You may tell students now that measuring spoons are available.

Connect what students are doing to how scientists design good procedures by reviewing *Designing Good Procedures* with the class. Emphasize that scientists trust experimental results that are repeatable by other scientists, and so they also need to know how to replicate their procedures. For this reason, procedures must be detailed and descriptive.

Also, emphasize measurement, precision, and errors. Let students know the importance of repeating trials so that they can be assured their measurement is reliable. It is also important for students to realize that however precise their measurements are, there will always be some unavoidable error which is at the very minimum due to the constraints of their measuring device.

2.3 Redesign Your Investigation

of times. Also, they would need to be watered in the same way. You would need to follow these rules every single time you watered each plant.

Measurement and Precision

It is also important to make the same measurement each time. In this example, you could count the number of leaves on each plant. You could also measure the height of each plant.

The tools you use can often affect measurement. You have limits to what you can see when you make a measurement. Be sure to consider how accurate the tools you use are.

Here is a checklist that you can use to make sure your measurements are consistent:

- Measure from the same point.
- Measure with the same units.
- Repeat **trials** for more **precision**.
- Start fresh. Do not compare data from before you make a change to a procedure to data collected after you make a change.
- Measure under the same conditions.

Errors and Measurement Constraints

Some groups in the class probably reported mistakes, or errors, they made as they were running their procedures. There are two kinds of errors to think about when you design procedures. Some mistakes are avoidable and others are not. For example, forgetting to start the stopwatch when the dish soap begins to flow down the plate is an avoidable mistake. These are the easiest kinds of errors to fix. You usually know when you have made this type of mistake and can easily do the test over.

But some errors are unavoidable. Every measurement has error that is impossible to avoid. If you have a ruler that measures in millimeters, you sometimes cannot tell if something measures half a millimeter or a quarter-millimeter. If you got a better ruler, there would still be a point at which you would have to estimate. Your results can only be as accurate as your measuring tools. Because scientists have constraints on their tools, they will always make measurement errors that are unavoidable. Scientists usually keep track of possible measurement errors when they report an investigation. This way, other scientists can judge how much to trust the results.

trial: one time through a procedure.

precision: how close together the measured values are.

Revise Your Procedure

15 min.

Lead the class in deciding upon a standard procedure for the investigation.

standardized: the same.

range: the zone between the largest and smallest results.

variation: a spread of data.

Revise Your Procedure

Now that you have looked at everyone's procedures and read about how to make procedures trustworthy, the class will decide on a **standardized** procedure that everyone will use to measure lava flow. A standardized procedure means that everyone will do each step the same way. Then you will be sure that the results obtained by different people or groups can be compared.

First, based on the results from each group, make a list of possible sources for the differences you see. Together, as a class, design a procedure that accounts for those differences.

Then, work as a class to identify possible sources of error. After your class has identified the possible sources of error, revise the procedure.

Your teacher will record and display the new procedure as the class designs it. You will need to record this procedure and keep it handy.

Reflect

Review and answer the following questions. Be prepared to discuss your answers with your class.

1. What are three or four key differences between your previous procedure and the new class procedure?
2. What are you now controlling better in the new procedure?
3. What effect do you think this new procedure will have on the **range** of results across groups?



What's the Point?

The points you thought about in this section are important in the *Lava Flow Challenge*.

Every group was using a similar procedure. However, your procedures were probably not identical. You probably saw a wide spread of data in the line plot. This is called **variation**. It is important to use the same procedure every time you test or measure something. Your results will then be consistent, and they will probably be repeatable. Creating a good procedure requires identifying the steps in the procedure very specifically, so it can be run the same way each time. It also requires identifying possible sources of error. This tells someone following a procedure how to do it to get repeatable results and what to be careful about as they are running it.

△ Guide

Next, lead the class in designing a new procedure that will give a more reliable answer. Students should be reminded to account for all factors and identify how the factors will be the same. Remind students that the goal is to develop one class procedure that every group can reproduce. By using the same procedures, students should get similar results.

One way to lead students in designing a new procedure is to model your thinking as you focus on one factor at a time. For instance, you might want to talk about the amount of dish soap first.

TEACHER TALK

“Let’s start with the dish soap. We could use different amounts of dish soap, and we could drop or place the dish soap differently on the plate. How much dish soap should we use? Some groups used more soap than others. What happened when groups used a lot of soap? What about when they used little soap? Did they put the dish soap on the plate when it was tilted or flat? How should we put the dish soap on the plate and start the experiment?”

As you think through the procedure with students, record the steps so that students will be able to evaluate the procedure and use it to run their investigations.

Next, use the bulleted list to help the class assess their procedure for replicability.

Assess

As you develop the procedure, listen to students’ ideas about how to measure consistently and precisely and how to control factors in investigations.

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META NOTES

Modeling scientific thinking is critical. Students do not have the experience to know what scientific thinking sounds like. By using a “think aloud” method in which you verbalize your thoughts, students will have a model for what scientific thinking might sound like. Modeling is particularly helpful here since this is the first time students have designed a procedure.

META NOTES

Designing a procedure is a good opportunity to assess students’ ideas about controlling factors. In this case, students should be thinking about how to measure all the things that might affect how fast the soap flows across the plate.

Reflect

10 min.

Lead students in comparing the old and new procedures.

Reflect

Review and answer the following questions. Be prepared to discuss your answers with your class.

1. What are three or four key differences between your previous procedure and the new class procedure?
2. What are you now controlling better in the new procedure?
3. What effect do you think this new procedure will have on the **range** of results across groups?

△ Guide

When the procedure is complete, go through the entire procedure with the class. Clarify any steps that might be ambiguous.

△ Guide and Assess

Use the *Reflect* questions to assess students' understanding of what they have done and why. You might have students write their answers to the *Reflect* questions, and then lead a discussion of students' responses. Alternatively, you might want to lead a discussion of the questions without having students answer them first.

1. Student responses should show an understanding of what was important about their revisions. The key changes will probably be in the steps where there were differences between groups' procedures.
2. The factors in the student lists should generally correspond to the key revisions to the procedure. In this discussion, emphasize changes that were made in the steps where there were differences between groups' procedures and where factors were not specified. Students may not understand the word "controlling." Consider giving an example such as controlling the tilt of the plate or the volume of dish soap used.
3. The new procedure should reduce the range of the results. This is the first time "range" is used. Emphasize to students that range is the spread in the data.



What's the Point?

The points you thought about in this section are important in the *Lava Flow Challenge*.

Every group was using a similar procedure. However, your procedures were probably not identical. You probably saw a wide spread of data in the line plot. This is called **variation**. It is important to use the same procedure every time you test or measure something. Your results will then be consistent, and they will probably be repeatable. Creating a good procedure requires identifying the steps in the procedure very specifically, so it can be run the same way each time. It also requires identifying possible sources of error. This tells someone following a procedure how to do it to get repeatable results and what to be careful about as they are running it.

Project-Based Inquiry Science

DIG 36

What's the Point?

5 min.

META NOTES

Sometimes an investigation shows there is no relationship between two factors. For example, say we were investigating how the amount of dish soap on a plate affected the amount of writing in a student's notebook. We would not expect there to be any relationship between these two factors so no matter how repeatable our procedures are we will always get a wide variation of results showing there is no relationship between them. However, it is important to note that even for an investigation like this, the results would be considered valid and accepted only if the procedures were repeated by many investigators who all found the same trends in their results and no one found any results significantly refuting the trends.

The reflection discussion you just had summarized most of what is in this segment. The one remaining thing is to introduce the word *variation*, which is the word that scientists use when they discuss how wide-ranging the data are. Scientists talk about the size of the variation.

As you finish the reflection discussion, listen for students recognizing the importance of using uniform procedures to get repeatable or consistent results. Standardized procedures usually reduces the variation.

Assessment Options

Targeted Concepts, Skills, and Nature of Science	How do I know if students got it?
Identifying factors that lead to variation is an important part of scientific investigations.	<p>ASK: What are some of the reasons you might get inconsistent results from an investigation?</p> <p>LISTEN: Students should recount some of the things that happened during their investigations that led to variation.</p> <p>ASK: What should the class graph look like when the investigation results are more consistent?</p> <p>LISTEN: The class graph should be more clustered.</p>

Targeted Concepts, Skills, and Nature of Science	How do I know if students got it?
<p>Scientific investigations and measurements are considered reliable if the results are repeatable by other scientists using the same procedures.</p>	<p>ASK: How can you verify that another researcher’s results are reliable?</p> <p>LISTEN: Students should know that if results are reliable, a researcher should be able get similar results by following the same procedure.</p> <p>ASK: How can changing your procedure from trial to trial affect your results? Give an example.</p> <p>LISTEN: Students should link changing procedures to varied results and use examples from their investigation.</p>
<p>Scientists often work together and then share their findings. Sharing findings makes new information available and helps scientists refine their ideas and build on others’ ideas. When another person’s or group’s idea is used, credit needs to be given.</p>	<p>ASK: Why is it important for researchers to have carefully controlled procedures?</p> <p>LISTEN: Students should recognize that a researcher needs to have results verified by peers, and that a researcher needs to establish procedures that peers can replicate.</p>

Teacher Reflection Questions

- What evidence do you have that students understand the need for a clear procedure that can be replicated and the need for repeatable results?
- What types of attitudes toward successes and mistakes have you observed in your students so far? For example, did some students compete for the best results in either investigation? What types of changes in these attitudes have you observed so far in this Unit?
- What did you do to model appropriate language during discussions? What ideas do you have for next time?

SECTION 2.4 INTRODUCTION

2.4 Investigate***How Fast Does the Model Lava Flow?***

◀ 1 class period*

Overview

In this section, students perform the lava flow investigation. Students run their class's standard procedure and collect data, which they share on a class line plot. Using the spread of the data to evaluate their new procedure, the class identifies ways that the procedure is still not precise enough. Students learn about different types of lava flow and once again revise their procedures and share their data. This time their results should be more consistent, providing evidence that a precise, standard procedure ensures consistent results.

Targeted Concepts, Skills, and Nature of Science	Performance Expectations
Scientists often work together and then share their findings. Sharing findings makes new information available and helps scientists refine their ideas and build on others' ideas. When another person's or group's idea is used, credit needs to be given.	Students consult their peers in planning and they share their results with their peers.
Scientific investigations and measurements are considered reliable if the results are repeatable by other scientists using the same procedures.	Students follow the class's standard procedure, analyze the class's data, and describe, based on their experiences, why scientists consider results reliable if they are repeatable.
When volcanoes erupt, magma reaches Earth's surface and is called lava. There are many different types of lava.	Students should be able to describe that there are different types of lava and that these may flow at different rates.

*A class period is considered to be one 40 to 50 minute class.

Homework Options

Reflection

- **Science Content:** Based on the results of your last investigation, what could you say about the results other researchers using your procedure would get? Why? *(Look for students linking the reliability or unreliability of the results to their usefulness for saying what results other researchers might get.)*
- **Science Content:** If you wanted to model and measure the flow rates of different types of lava (basalt, andesite, dacite, and rhyolite), what changes would you need to make to your lava model? How would you change the materials to better model different lavas? *(The model would have to include new test materials. The materials would need to have flow rates that mimicked the different types of lava. So slow-flowing lava might best be modeled using honey or molasses, while fast-flowing lava might best be represented by water or milk.)*
- **Science Content:** You have a set of measurements of the time it takes a pendulum to swing back and forth 10 times. The results are as follows:

Trial	Time(s)
1	14.7
2	15.1
3	15.3
4	21.3
5	14.9

Make a line plot for these results. Do you think all the trial values are reliable? Why or why not? Can you reliably say how long it takes the pendulum to swing back and forth 10 times? If so, how long? *(Check to see if students identify the outlier at trial 4, and if they exclude the trial from analysis.)*

SECTION 2.4 IMPLEMENTATION

2.4 Investigate**How Fast Does the Model Lava Flow?****Run Your New Procedure**

Now that you have a new procedure, your team should be able to produce more reliable results. Your class will soon collect another set of data and produce a new line plot. As a class, update the criteria and constraints of the challenge if you need to.

Follow your new procedure. Use the materials listed. Obtain results for 5 to 10 trials.

Record your results on the same sheet of paper you used to record your procedure. Be prepared to share your results with your class and teacher. You will have 10-15 minutes to perform your procedure and collect your data.

Communicate Your Results**Share Your Data**

Use another sheet of graph paper to make a line plot from the new data.

As before, each group will read aloud their results. Everyone will plot them on the graph paper. Each group should report any problems they had running the procedure (e.g., mistakes, spills).

Analyze Your Data

After your class creates the second line plot, answer the following questions together.

1. How do the results from this investigation compare to the ones from your first set of trials?
2. Did all groups get results similar to yours?
3. Do you trust these results more? Why or why not?

Materials

- plastic plates
- stopwatch
- model lava (bottle of dish soap)
- paper towels



DIG 37

DIGGING IN

◀ 1 class period*

2.4 Investigate**How Fast Does the Model Lava Flow?****Run Your New Procedure**

10 min.

Guide students to run an investigation with the new procedure that the class designed in Section 2.3.

△ Guide

With the class, update the list of criteria and constraints from *Section 2.1*. The criteria and constraints should include specific requirements for reliable results, such as: groups need to carefully follow the procedure the class decided upon and they need to ensure that they are all using the same materials.

◇ Get Going

Next, distribute the materials or have students get them from a materials station and ask students to begin their investigations, emphasizing that pairs should record their results on the same sheet of paper where they wrote their procedure. One student can record results while the other puts the

*A class period is considered to be one 40 to 50 minute class.

soap on the plate, as they did in their first investigation. Make sure students know how long they have (10 or 15 minutes) and how many times to repeat the procedure. Pairs should run five trials if your class is large and 10 if your class is small. This ensures that the class will generate enough data (about 70 total trials total for the class).

□ Assess

While students are running their investigations, you can observe how closely groups are following the class's standard procedure. If any group is doing something differently from the rest of the class, note the difference as something to discuss later. Also, look at data to get an idea of how consistent they are. Listen for students' ideas about carefully following a procedure or recording data.

Communicate Your Results

10 min.

Create a class graph of students' data after all pairs have finished running their investigations.

Communicate Your Results



Share Your Data

Use another sheet of graph paper to make a line plot from the new data.

As before, each group will read aloud their results. Everyone will plot them on the graph paper. Each group should report any problems they had running the procedure (e.g., mistakes, spills).

△ Guide

First, make sure that all students have graph paper. Then, briefly review how graphs help scientists share and analyze data, especially when there are many data points and they are looking for trends. Using a clean transparency, ask each pair how many seconds they recorded for each trial. For each result, put an X on the graph. Remind students to record the results of the class on their own graphs.

TEACHER TALK

“We’re going to plot your data on a graph just like we did last time. Remember, each of the columns on the line plot represents a number of seconds that it might take for the dish soap to flow down the plate. If a group got 40 seconds, I’ll put an X over the 40-second mark on the graph. You should also do this on your graph. When we are finished, I will allow you some time to check your graph against the class graph.”

running the procedure (e.g., mistakes, spills).

Analyze Your Data

After your class creates the second line plot, answer the following questions together.

1. How do the results from this investigation compare to the ones from your first set of trials?
2. Did all groups get results similar to yours?
3. Do you trust these results more? Why or why not?

DIG 37

DIGGING IN

Analyze Your Data

35 min.

Lead students through an evaluation of their data looking for evidence that their procedure is refined enough to limit the range of the results. If the data are still very scattered, students will need to revise their procedure once again.

△ Guide

Lead students to examine their graphed data and critique their new procedure. Begin by looking at the spread of data and then the precision of the procedures. The goal is to evaluate whether the procedure must be refined and repeated once again to get a result reliable enough to report to the town. The answers to the first two questions in the student text will provide evidence for discussion about the trustworthiness of these new data (question 3). Use these points to guide the discussion:

1. If students have effectively redesigned their procedure, they should find that the results of the second investigation are more consistent. Consistent data should have less range and be more clustered on the line plot.
2. It is likely that the class will have a few outliers. Students may be able to connect these with mistakes or accidents of some kind that happened during the investigation. Encourage students to share the circumstances around the outliers. This is a good opportunity to discuss what should happen to the numbers that are obviously faulty. Should students disregard them, repeat them, or average them in? Each decision has different implications for the investigation. You might also discuss the fact that no measurement is ever exact. There is always some range of values that the measurement may fall within.
3. Students may say that results that are more consistent can be repeated, and results that can be repeated are more reliable or trustworthy. Move the discussion toward how scientists determine if a result is trustworthy. Scientists call results trustworthy or reliable if the trends in the results found by others following the same procedure are the same.

As students evaluate the results of the investigation, discuss whether the results are consistent enough to determine a speed for the lava flow.

META NOTES

When an experimental data point is an outlier, it is usually due to a blunder or mistake while running the investigation. If this is the case, then the data point should be noted as due to a mistake and what that mistake was, and should not be included in the data analysis. If possible, that investigation should be run again to collect another data point. If there is no evidence that the outlier is from a blunder, then it should be included in the data analysis.

META NOTES

The average speed can be calculated by taking the total distance traveled divided by the total time. In this case, the distance would be that of the dish soap across the plate (which should be measured with a ruler) and the time would be the average time the class obtained, whose reliability depends on how clustered the data are.

META NOTES

Ideally, students should revise and repeat their procedure one last time, after reading about lava. If you decide that the students have revised enough (based on how clustered their data is) and are ready to move on, discuss lava types and the challenge and complete this *Learning Set*. If you decide that students need one more iteration, continue from here.

META NOTES

Groups may still be straying from the standard procedure, causing varied results. If you observed any groups straying, you can lead students to this source of variation. If groups are following the standard procedure and still finding different ways of doing things, then the procedure needs to be more precise, and you can lead them to this after the reading.

TEACHER TALK

“You revised your procedure. How did the new procedures affect the class’s results? How consistent are the results? Can you account for any data points that seem too high or too low? What do you think you could do to revise the procedures again and make the data even more consistent?”

Discuss ways in which the procedure can be improved.

TEACHER TALK

“Were there any things groups were doing differently? Could your procedures have been more precise? What else could you do to get more consistent results?”

△ Guide

Guide students’ reading through the types of lava.

Next, let students know that they will learn a little about the different types of lava, and where those different types of lava are found. Students could think about how they might revise their procedure to model the worst-case scenario for the challenge of the Hawaiian town near the volcano.

TEACHER TALK

“The reading includes information about lava. Each of the different types of lava flow differently, and that’s something to pay attention to as you read this. As you read more about the lava types you should think about which type of lava flows fastest.”

First describe again the difference between magma and lava. Magma is melted rock inside Earth; lava is melted rock that reaches Earth’s surface. Lava moves away from the volcanic vent. As it moves, it cools and moves more slowly. How fast lava flows also depends on the type of lava. The more silica in the lava, the more viscous the lava will be, and the more slowly it will flow—usually.

Next, briefly discuss the types of lava.

Emphasize that the two common types of lava commonly found in Hawaii are a'a and pahoehoe. This is not clear from the reading.

A'a (pronounced "ah-ah") lava is slightly viscous—not as thin and runny as other types of basaltic lava. A'a flows are typically three to five meters thick and jagged and sharp.

Pahoehoe is less viscous than a'a, but a'a generally flows more quickly. Pahoehoe flows are usually less than one meter thick and cool into rounded swirls and rope-like patterns with smooth surfaces.

Emphasize that a'a lava flows have more volume than pahoehoe. This should cause students to consider increasing the amount of dish soap they are using in their experiment.

Andesite has slightly more silica content and is more viscous than basaltic lava, so it flows more slowly. It sometimes cools and hardens in large blocks. Dacite has more silica content and is more viscous than andesite. Rhyolite has a lot of silica content and is very viscous.

META NOTES

The reading does not define viscous. Viscosity is a measure of resistance to flow. In general materials that are more viscous, flow more slowly. For example, when compared to water, lava is very resistant to flowing, it is 1000 times more viscous than water.

META NOTES

The more viscous a fluid is, the more it resists flow in most cases. However, note that a'a lava is more viscous than pahoehoe but generally flows more quickly than pahoehoe. This is counterintuitive. Many factors contribute to this.

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Lava

Lava is melted rock that reaches the surface of Earth. There is also melted rock inside Earth. Melted rock is called magma as long as it stays underground and does not reach the surface.

Scientists describe lava by its physical appearance—the way it looks. Several things affect the way lava looks:

- what it is made of (the kinds of molecules and atoms),
- the temperature at which it is flowing,
- the kinds of crystals that form, and
- the land it is flowing over.

When lava comes out of a volcanic vent, it can range in temperature from about 700°C to about 1200°C (1300°F to 2200°F). As it moves away from the vent, it starts to cool. Just like hot fudge on ice cream, lava gets more viscous, or thicker, as it cools. Hotter lava is generally thinner than cooler lava. This also means that lava slows down the farther away it gets from the vent it first erupts from.

The composition of lava, or what it is made of, depends on the location of the volcano. You will study more about this later on.

Basaltic Lava

Most lava is basaltic. This type of lava is thin and runny. It has lower silica content than other types of lava. Silica is the same thing sand is made of. The two types of lava commonly found in Hawaii are both basaltic.



A'a lava as it cools. Even after the lava cools, you would not want to walk on it with bare feet.



An a'a flow appears to eat up cars and a road. The cars give you an idea of how thick the flow is.

A'a

A'a (pronounced "ah-ah") is a slightly viscous lava. This type of lava usually comes out in flows that are three to five meters (approximately 10-16 ft) thick. A'a flows are jagged and extremely sharp. A'a in Hawaiian means "hard on the feet." Even though a'a is viscous, it flows quickly.

2.4 Investigate

Pahoehoe

Pahoehoe (pronounced "pa-hoey-hoey") is generally less viscous than a'a. This means that it flows more easily. It usually makes flows that are less than one meter (approximately 3 ft) thick. Pahoehoe flows are very hot, over 1000°C (about 2000°F). The word pahoehoe means "like a rope." As the lava cools, it hardens into rounded swirls and rope-like patterns with a very smooth surface.



New pahoehoe cools off. The ropes are caused by the way the lava ripples just before it hardens.

Andesite

Andesite has slightly higher silica content than basaltic lava and is more viscous, meaning it is more resistant to flow. It sometimes cools and hardens into large blocks, sometimes called block lava.



The andesite in this photograph came from lava that contained more silica than basaltic lava. This flow is about 12 m (approximately 40 ft) thick.

Dacite

Dacite has higher silica content than andesite and is more viscous.



Because dacite is more viscous, it usually does not flow far from the volcano. Dacite often forms steep-sided mounds called lava domes.

Rhyolite

Rhyolite is very viscous lava with high silica content. It is found in many of the lava flows in California and the western United States.

When you modeled the viscosity of lava, you modeled only one type of lava flow. But, if you had more time, you would want to know what type of lava flow the town was likely to experience. Look at the chart on the next page. It shows the four types of lava arranged by viscosity: basalt, andesite, dacite, and rhyolite. Basalt flows quickly because of its components, temperature, and cooling rates. Rhyolite lava has higher viscosity. It is thicker and flows more slowly. As you move from left to right across the chart, through the different types of lava, each type is higher in viscosity.



Rhyolite has beautiful flow patterns. It is made from much more viscous lava than the Hawaiian a'a or pahoehoe.

Revise Your Procedure

up to 10 min.

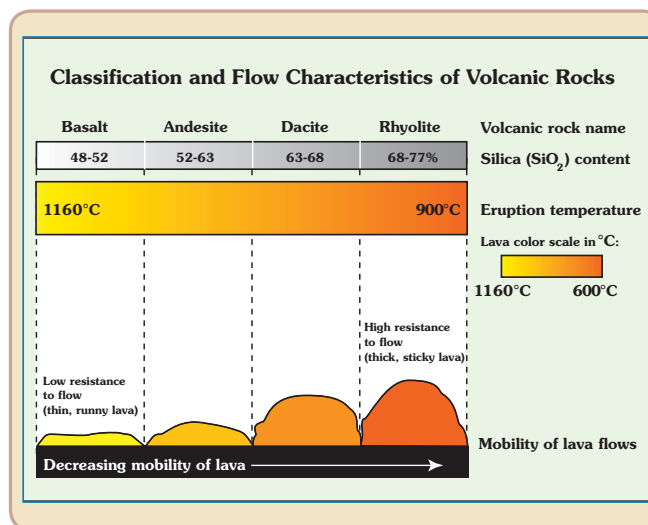
If you have decided that the class will do a third iteration, lead them in revising their procedure once more.

META NOTES

A'a lava flows have been recorded to have initial advance speeds between 0.3 m/s and 2.7 m/s. These speeds would correspond to students measuring times for the dish soap across a distance of about six inches and a 45° tilted plate between six seconds and 0.06 seconds.

Pahoehoe speeds are usually less than 0.3 m/s (this would be more than six seconds across a distance of about six inches and a 45° tilted plate).

Lava has been recorded to flow much faster within already-formed channels with speeds as high as 15 m/s.



Revise Your Procedure

Think about and discuss how the new, more specific procedure provides a closer answer to the question: *How fast does the model lava flow?*

You might find that the range of results is still too large for you to trust. If so, come up with fixes to create an even better procedure. You may also want to discuss what you just learned about different types of lava and decide if it affects any aspects of your procedure.

Use this new procedure. Produce a third set of data that are more consistent. Be sure to run your procedure under the same conditions as you did before. You may need to do this part of the activity at home. As before, plot these new results on another line plot. Do you trust these results more? Why?

△ Guide

Ask students if there is anything they think they need to change in their procedures based on the new information they have about lava. Students should realize that a'a lava would be the worst-case scenario and they may want to increase the volume of dish soap they are using.

If you decided the class should revise their procedures again, then guide students to think about the problematic differences and parts they determined earlier. Require them to be more specific as you lead the class in designing a new procedure. Since this is possibly the third time students have worked on this procedure, focus on refining or adjusting the current procedure rather than starting from scratch.

TEACHER TALK

“Scientists use iteration to improve their scientific procedures. You have revised your procedures and seen what happened to your results. Do we need to “tighten up” the procedures to make it even more accurate? What did you notice about the procedures and results of others? What slight differences did some groups have in their procedures that would make their results differ?”

META NOTES

When you monitored groups you may have noticed slight differences in some groups implementation of the procedures. Guide students to this source of inconsistent results here.

As students specify steps, record the new procedure.

Once the class has revised their procedure, have students run their investigations. Graph the new data on a line plot with the class, and help them analyze the data and evaluate the results.

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Reflect

15 min.

Now that students have two or three iterations of their investigation, lead a class discussion comparing the procedures and resulting graphs across the investigations.

Reflect

After your class creates the second, or possibly third, graph, answer the following questions. Be prepared to discuss your answers with your class.

1. What did the distribution, or spread, of data points on your latest line plot look like? What do you think this says about how precise your team has been at determining how fast lava flows over the land?
2. Do you think it would ever be possible, given the materials and conditions you have in the classroom, to find an exact answer? Why or why not?
3. What do you think it would take to find an exact answer?

Discuss your answers and how they may help you better achieve the *Lava Flow Challenge*.

What's the Point?

Revising your procedure was important for your *Lava Flow Challenge*. By developing a precise procedure for everyone in the class to use, your results became more consistent. The town council is relying on the "right" answer to their question of how fast lava flows over the land. The more consistent your class results are, the more the town council will trust your results.



DIG 41

DIGGING IN

△ Guide

To get students thinking about the importance of precise and standardized procedures, have students look again at the graphed data from each iteration of their investigation.

If students have three graphs, first focus on comparing the graphs and procedures. If they did only two, then they've made the comparison already.

Focus students' attention on the spread of the data and remind them of the changes they made in their procedures that led to the improvements in the reliability of the data.

TEACHER TALK

“So how has the spread of the data changed? What changes in your procedures could have changed the spread of the data?”

Listen for the following in students’ answers and guide the class toward these responses if necessary. Try to always help students make a connection between their responses and how they will help them better achieve the challenge.

Students’ responses should demonstrate an evaluation of the data, and an understanding of what the distribution of a data set indicates. For example, if students say the data are clustered tightly around a number, they should use this as evidence that they have used precise procedures. If the students say the data are still scattered, they should use this as evidence that their procedure still isn’t precise enough. In order to achieve the challenge they need to have results that are trustworthy. The results are more trustworthy when their data are more clustered.

TEACHER TALK

“How would you describe the range or spread of the data on the each graph? On which graph do you see the data most spread? Why do you think there is less range on this graph (present the second or third graph)?

What were the most important changes you made to your procedure to improve data collection? What changes do you think made data collection more difficult and perhaps less accurate? Is the new procedure more or less precise than the last procedure? Did all groups follow the procedure?

How does this information help you to solve the challenge?”

Students’ responses should be based on the evidence from the procedures they have run. The class procedure is now more precise, and their data should be more clustered, but some variation probably remains. From this, they can conclude that it is unlikely that they could ever get an exact answer with the materials and conditions in the classroom.

Students might say that a more exact measurement could be obtained by using more precise tools to measure the tilt of the plate or the amount of soap. However, they should recognize that all tools have limited precision, and thus no measurement is ever exact. Students should realize that there is no “exact” value, but that they can still have trustworthy results if, when following the same procedures under the same conditions, their results are repeatable.

META NOTES

An example of limited precision is the digital stopwatch. The stopwatch will give you measurements in increments of hundredths of seconds, but there is still some uncertainty in the thousandths of seconds range. At the very best, the stopwatch has an uncertainty of $\frac{1}{2}$ its smallest increment.

What's the Point?

5 min.

the Lava

What's the Point?

Revising your procedure was important for your *Lava Flow Challenge*. By developing a precise procedure for everyone in the class to use, your results became more consistent. The town council is relying on the "right" answer to their question of how fast lava flows over the land. The more consistent your class results are, the more the town council will trust your results.



DIG 41

DIGGING IN

META NOTES

At this point, students may be ready to discuss their ideas about what timing they might give to the town for their evacuation plan. This discussion could take 15 minutes and would require students to use evidence from their investigations to support their decisions. It is important that students understand that they are making a decision based on their collected data. The *Big Question* of the *Learning Set* will return the students to thinking about how scientists work together to solve problems. The *Back to the Big Question* section does not focus on helping the town make an evacuation plan.

◆ Evaluate

As students reflect on their investigations, make sure they make the link between precise procedures and more reliable and trustworthy results.

TEACHER TALK

“The first time we graphed our results, the range of the data was very large. Your results were spread out all over the graph. So you made your procedure more precise, and then the data were more consistent, the range was much smaller. It makes sense that revising your procedure to make it more precise and then making sure everybody is using the same procedure, increases the reliability of the data.”

Assessment Options

Targeted Concepts, Skills, and Nature of Science	How do I know if students got it?
<p>Scientists often work together and then share their findings. Sharing findings makes new information available and helps scientists refine their ideas and build on others' ideas. When another person's or group's idea is used, credit needs to be given.</p>	<p>ASK: How would your conclusions be different if you had run all of the trials by yourself, without your classmates?</p> <p>LISTEN: Students may suspect that their trials would have been consistent, but they should recognize that they would not have been able to verify that other researchers would get similar results.</p>
<p>Criteria and constraints are important in design.</p>	<p>ASK: How do you know if measurements are reliable?</p> <p>LISTEN: If they can be repeated by using the same procedures of measurement, then they are reliable.</p>

Teacher Reflection Questions

- How did students make progress in graphing and analyzing data from the beginning of this *Learning Set* to this section? What evidence do you have that students understand the need for repeatable results?
- How did you encourage students to stay focused on the procedural steps and continue to collect data that was reliable?
- In PBIS the emphasis is on collaboration and so having students talk to each other is critical. What observations did you make during the class that demonstrate that students were engaged and sharing their ideas with their peers in small group discussions and class discussions? What ideas do you have to encourage student-to-student interactions during discussions?

BACK TO THE BIG QUESTION IMPLEMENTATION

Back to the Big Question

10 min.

Now that the class has completed the Lava Flow Challenge, have students reflect on what they have learned and how it connects to the Big Challenge of the Launcher Unit: *How do scientists work together to solve problems?*

META NOTES

Students should say that, like scientists, they designed standardized procedures and worked towards repeatable results. During the investigations, they should have made their procedures more specific and ensured that everyone was using the same procedures. And scientists consult with each other, share their results, and revise their investigations.

**Learning Set 2****Back to the Big Question***How do scientists work together to solve problems?*

You and your classmates have been trying to find the answer to a question. In the end, you have probably realized that it would be very difficult to find an exact answer. But, as the different groups in the class used more similar procedures, their answers got closer to each other. You found that the way you collect data affects the answers you can find.

The first time everyone tried to determine how fast the dish soap ran across the plate, each group had different results. That is because each group used a similar, but not identical, method. The class then came up with a standard procedure. When everyone followed this procedure, the results were closer to each other. Your data became more consistent. You and others could trust your data.

There are three likely sources of inconsistent data:

- Different procedures are used for different trials.
- Factors that can affect the measured result are not carefully controlled.
- The tools used have constraints.



It is important for scientists that the results of their experiments can be trusted. They must develop very precise methods that give similar results each time. To check scientific results, other scientists repeat investigations to see if they also get the same results. Scientists can trust the work of other scientists if another scientist can replicate the investigation and get the same results.

Project-Based Inquiry Science

DIG 42

△ Guide

Use the student text to help students connect their experiences in this *Learning Set* to the *Big Question* of the Unit, highlighting the three likely sources of inconsistent data. Pose questions to connect their experiences with the *Lava Flow Challenge* to the *Big Question*.

TEACHER TALK

“What did we do in these investigations that helped us to get more reliable results?”

How did the way you worked together change during your investigations?

What were you doing in these investigations that might be like what scientists do?”