UNIT 1 : EVIDENCE & ITERATION IN SCIENCE

v 1.0

SCIENTIFIC THINKING FOR ALL : A TOOLKIT

ACTIVITY 2

Validating Measurements

LABORATORY

ACTIVITY 2

Validating Measurements

ACTIVITY SUMMARY

Students conduct an investigation into one water quality indicator: pH. They measure pH values, using different techniques and compare their pH values in order to validate their results. They apply the concepts of accuracy and reliability of data. As a class, they discuss the role of human senses and other scientific tools in gathering data and validating results.

ACTIVITY TYPE
LABORATORY

NUMBER OF 40–50 MINUTE CLASS PERIODS
2

KEY CONCEPTS & PROCESS SKILLS

1 New scientific tools and techniques contribute to the advancement of science by providing new methods to gather and interpret data and can lead to new insights and questions. Technology can enhance the collection and analysis of data.

2 Various observations of a single phenomenon from human senses and scientific tools can be used to verify the accuracy of evidence.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence. *(Science and Engineering Practice: Engaging in Argument from Evidence)*

CONCEPTUAL TOOLS

VOCABULARY DEVELOPMENT

control

(assumed prior knowledge)

standard of comparison for checking or verifying the results of an experiment; results of the experiment are compared with the control in order to see if the variable changed in the experiment caused any effect

pH

(assumed prior knowledge)

a measure of how acidic or basic a solution is; the pH scale measures the relative concentration of hydrogen ions (H+), utilizing a scale where 1–6 is classified as acidic, 7 as neutral (neither acidic nor basic), and 8–14 is classified as basic

turbidity

a measure of the clarity of water that indicates the presence of suspended particles such as soil or algae

validation

process of determining the accuracy of a measurement

BACKGROUND INFORMATION

Scientific Validation

When using scientific tools, scientists must check how much each instrument differs from the standard at the start and end of an experiment (and sometimes in the middle of the experiment, if it is a long-term experiment). For example, tape measures can stretch, so their accuracy should be checked at the beginning and end of an experiment. If a person visually assessed something, such as the behavior of an organism, it must be a repeatable observation. The observation process must be validated for the same result to be consistently obtained—for example, by detailing exactly the behavior observed and how it is recorded. If more than one person collects data, it is essential to validate, at regular intervals, that everyone is collecting data in the same way; otherwise, certain items are recorded more frequently or less frequently as different people focus on different aspects or provide more detail or less detail. If several people participate in a visual assessment, it is important to validate their ability to interpret an item in the same way—for example, the taste and color differences in fruit or other foods.

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 1.2
  "Scoring Guide: Evidence and Trade-Offs (E&T)"
  (OPTIONAL)
- ITEM-SPECIFIC SCORING GUIDE: Activity 2 Build Understanding item 5
- 6-8 CUPS OF BOILING DISTILLED WATER
- LARGE HEAD OF RED CABBAGE
- LARGE GLASS CONTAINER
- KNIFE
- STRAINER
- BLENDER
  (OPTIONAL)

FOR EACH GROUP OF FOUR STUDENTS

- 100 mL BEAKER OF RED-CABBAGE JUICE
- DROPPER BOTTLE OF HOUSEHOLD AMMONIA
- DROPPER BOTTLE OF DISTILLED WATER
- DROPPER BOTTLE OF HOUSEHOLD VINEGAR
- CUP OF DRINKING WATER SAMPLE
- pH PAPER WITH pH SCALE
- pH METER WITH PROBE
- CUP OF WATER
- EMPTY CUP
- PAPER TOWEL

FOR EACH PAIR OF STUDENTS

- 5 SMALL BEAKERS, LABELED A–E
  (or empty petri-dish bases or a tray with multiple wells, such as a SEPUP tray)
- 10 mL GRADUATED CYLINDER
- SHEET OF WHITE PAPER
- DROPPER
- STIR STICK

FOR EACH STUDENT

- SAFETY GOGGLES
- LAB COAT
- STUDENT SHEET 1.3
  "Writing Frame: Evidence and Trade-Offs"
  (OPTIONAL)
- STUDENT SHEET 2.1
  "Data Tables"
  (OPTIONAL)
- VISUAL AID 1.2
  "Scoring Guide: Evidence and Trade-Offs (E&T)"
  (OPTIONAL)

Chop the cabbage into small pieces until you have about 4 cups of chopped cabbage. Place the cabbage in a large beaker or other glass container and add boiling water to cover the cabbage. Allow at least 10 minutes for the color to leach out of the cabbage. Alternatively, you can place about 4 cups of cabbage in a blender, cover it with boiling water, and blend it. Filter out the plant material to obtain a purplish-colored liquid (the exact color depends on the pH of the water). Using distilled water, this liquid should have a pH of about 7. Depending on your number of teaching periods and your class size, you may require additional red-cabbage juice. Each pair of students will need approximately 20 mL of this liquid.

Each pair of students will use approximately 25 mL of each of the 4 liquids. Based on your class size and number of periods, determine the amount of liquid you will require for the activity. Label the beakers A–E. Empty petri-dish bases, or a tray with multiple wells (such as a SEPUP tray), can be substituted for the beakers.

Note that the activity can be modified to address the availability of materials in your classroom. If you do not have access to pH meters, have students skip Procedure Steps 15 and 17.

SAFETY NOTE

Remind students to make observations using only sight and smell and to not eat or drink any chemicals.

TEACHING NOTES

Suggestions for **discussion questions** are highlighted in gold.

Strategies for the **equitable inclusion** are highlighted in blue.

GETTING STARTED (10 MIN)

1 **Brainstorm water quality indicators as a class.**

- Remind students of how the scenario of Skipton raised the issues of water accessibility and water quality. Some residents observed cloudiness, a possible indicator of contaminants. Ask, What are other indicators of water quality? Elicit students' thinking and make a list of student responses. Students may be aware of smell, appearance (color, clarity), salinity, temperature, oxygen levels, the possible presence of microbes, and the possibility of chemical contaminants. They may also identify pH, which was raised in the Skipton scenario.

2 **Have students read the Introduction in the Student Book.**

- Review the use of **pH** and **turbidity** as water quality indicators.
- If students are completely unfamiliar with pH, refer to "Scientific Review: pH" found at the end of the Student Book activity to review basic concepts about pH.
- Discuss the concept of **validation**, a process of determining the accuracy of a measurement. For example, a weighing scale can be validated by measuring the weight of several objects of known weights to determine if the scale is accurate. Students may have had experience with this if they had to use a scientific balance that provided inaccurate measurements. Scientific tools can be validated by comparing measurements taken with the tool with other reliable values, such as those made with other instruments or even by human senses or by using known values to determine the tool's accuracy.

PROCEDURE SUPPORT (30 MIN)

3 Review classroom safety expectations.

- Remind students to wear lab coats and goggles and to follow all classroom safety rules. Review the Safety Note in the Student Book and the proper method for smelling chemicals in science by wafting, as described in Procedure Step 2.

4 Students make observations of each of the four liquids.

- Students begin by using their senses to gather data. They are able to make observations of odor and appearance and are asked to make pH predictions.
- Discourage students from trying to research the pH of each liquid in advance. A goal of this procedure step is to determine the data that can be gathered by human senses, as well as its limits.

5 Students measure pH, using red-cabbage juice in Procedure Part B.

- If students are not familiar with the term control, remind them that a **control** is a standard of comparison for checking or verifying the results of an experiment. Comparing the experimental results with the control allows them to see if the variable they changed in the experiment caused any effect.
- In this unit, laboratories and card-based investigations use hands-on materials to support student learning. Certain student populations—including girls, gender non-conforming students, and English learners (ELs)—often take on roles in which they do not directly engage with hands-on materials, such as recorder and observer. Incorporate strategies to ensure that all students participate over time. For example, in activities like this one in which students conduct the investigation in groups of four, one strategy is to assign roles (such as group leader, recorder, observer, and timekeeper) ahead of time and then rotate them periodically. Another strategy is to create specific groupings of four that might encourage greater participation. Decide which strategy you will use to best support your student population.
- Students can record their lab results in a science notebook. Alternatively, you may wish to provide copies of Student Sheet 2.1, "Data Tables," which contains all the data tables to be completed during the procedure. Sample student responses to all the data tables are shown on Student Sheet 2.1 found at the end of this activity.
- You may wish to review the color variation described in Table 2.3. Violet is a deeper shade of purple that contains slightly more blue than red.

6 **Students measure pH using pH paper in Procedure Part C.**

- Different commercially available pH papers have different color scales. Review the color scale of the pH paper being used in your classroom as needed. You may wish to develop a common language to refer to each color on the scale—for example, pH 7 is spring green, while pH 8 is grass green.
- To support color-blind students, consider using a pH paper that does not utilize red/green contrast but instead uses intensities of a single color, such as green. Or install a smartphone app that helps identify colors for those with color blindness and allow students to use the app as needed. Be sure there is good lighting to examine the pH paper.
- Students can use the information in Table 2.3 or in the Scientific Review to determine whether each liquid is acidic, basic, or neutral.

7 **Students measure pH, using pH meters, in Procedure Part D.**

- If you have pH meters available, have students use them to measure the pH of each liquid. Methods to calibrate and measure pH with pH meters can vary, so provide appropriate direction to your students as needed.
- You may want to discuss how the accuracy of scientific technologies such as pH meters are dependent on their calibration. A miscalibrated meter can result in inaccurate data.

8 **Students compare their pH measurements.**

- In Table 5, students compare their predicted and measured pH readings for the four liquids. They should see some consistency in their readings, leading to reliability, and recognize that they gathered more accurate data by using the pH meters.
- Discuss variability in students' observations of color and how this may have affected their pH readings. Review the idea that scientific data can require the interpretation of observations and that part of the process of science is constructing methods to reduce such variability. Variability is reduced by validation measurements and by ensuring the accuracy and reliability of data.
- Students validated the measurement of pH by comparing different pH measuring techniques: red-cabbage juice, pH paper, and pH meters. These techniques let students perceive phenomena more completely, precisely, reliably, and accurately than senses alone.

SYNTHESIS OF IDEAS (10–15 MIN)

9 **Discuss the role of human senses in validating results from scientific tools.**

- Use Build Understanding items 1–4 to discuss the usefulness and limits of human senses for gathering data.
- Students' predicted pH values may vary widely from the measured values. Some phenomena, such as pH level, are not directly perceivable by human senses alone, only by instruments such as pH strips or pH meters. Ask, How can people be confident that they are observing real differences in pH levels when pH cannot be directly seen by people? What could increase your confidence level in such measurements? Students should respond that multiple measurements from scientific tools, such as pH meters, can be used to validate pH. More complete scientific explanations, such as understanding the mechanism behind a phenomenon, can result in increased confidence levels.
- Ask, In what situations are scientific tools used to validate data from human senses? Think about everyday situations in which data gathered by your senses requires you to get more detailed information from scientific tools. Sample responses may include temperature, weight, height (or length), distance, time, speed, heart rate, altitude, etc.

10 **Relate the concept of pH to the Skipton scenario.**

- Build Understanding item 5 applies the concept of pH to the Skipton scenario.
- You can use Visual Aid 1.2, "Scoring Guide: Evidence and Trade-Offs (E&T)" to assess Build Understanding item 5. A sample Level 4 response is included in Sample Responses to Build Understanding and on Student Sheet 1.3.

EXTENSION (10 MIN)

11 **Use the Extension as an opportunity for advanced learning.**

Students can find out more about their local water quality by researching publicly available information provided by local water authorities. Most public water authorities have an annual report of local water quality that can be accessed online or is mailed to local residents. Data is likely to include both biological and inorganic measurements, unregulated contaminants, and disinfection byproducts. Facilitate students' research by providing the name(s) of your local water authority and/or provide website links for students to get more information about local water quality.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

1. **Explain how using pH probes (or pH paper) did or did not validate the use of red-cabbage juice as a pH indicator. Support your answer with evidence from your experimental results.**

   `HINT: Consider how similar or different the resulting pH values were for each tested liquid.`

   The pH paper validated the use of the red-cabbage juice because we had similar pH values for all 4 liquids. For example, the vinegar had a pH of 3–6 based on the dark red color of the cabbage juice, and it had a pH of 3, using the pH paper.

2. **Scientific explanations depend on relevant, accurate, and reliable data.**

   a. Compare the pH measurements you made, using different tools. Describe how accurate your measurements of pH were in this activity.

   The pH data were accurate with a specific range, as measured by the different techniques. The pH readings may vary because people can see and identify colors, such as dark pink vs. red, differently.

   b. Compare your pH measurements with those of other groups. Based on your comparisons, describe how reliable your measurements of pH were in this activity.

   The pH data was reliable because almost all the groups measured the pH within a range of 1 when using the pH paper and the pH meter. The pH data based on the cabbage juice was less reliable because people had very different results.

3. **What does this activity tell you about data from human senses vs. scientific testing?**

   pH cannot be observed by human senses and needs scientific testing to be measured. Different techniques can contribute to increased reliability and accuracy.

4. **Beginning in the 1920s, electrochemical probes, such as the one shown here, began to be used to measure pH more accurately. Advances in technology have resulted in miniature devices that can test pH inside living cells. Why would these technologies be preferred over color indicators such as pH paper and cabbage juice?**

These new technologies provide more precise pH measurements that are more reliable and accurate. They can also be used to measure the pH of more materials than color indicators.

5. **E&T Scoring Guide**

Levels of pH decrease as temperature increases: a 10°C (50°F) increase in temperature will reduce the pH by 0.2. In order to reduce energy use and save money, a factory sited along the Mizu River in Skipton releases treated wastewater back into the river at a temperature of 27°C (80°F) and a pH of 6.3. The average temperature of the river is 18°C–24°C (65°F–75°F) in the summer and 2°C–7°C (35°F–45°F) in the winter. The factory supervisor calculates that as the water cools, it will result in an acceptable pH.

Should the local government require additional treatment of the wastewater before it is released? Support your answer with at least three pieces of relevant evidence from this activity and identify the trade-offs of your decision.

HINT: You may want to first review the introduction and Scientific Review for this activity.

LEVEL 4 RESPONSE

The government should require that the wastewater be treated more before being released. The pH of drinking water is expected to be within a range of 6.5–9, and the company is releasing it at 6.3, which is lower than drinking water standards. Also, the ideal pH range for aquatic organisms such as snails is higher (over 7). Even though the pH of the water might go up as the water cools, it is still going into the river as being too acidic. The trade-off is that treating the water will use more energy and cost more money. People who disagree with my decision might say that the difference in pH from 6.3 to 6.5 is quite small, and the water will be diluted once it is released into the river.

LEVEL 3 RESPONSE

The government should require that the wastewater be treated more before being released. The water being released is at pH 6.3 and 27°C, which is too low a pH for aquatic organisms and hotter than the warmest average temperature of the river. Even though the pH might go up as the water cools, it shouldn't go into the river if it is that different from the river water. The trade-off is that treating the water more will cost more.

LEVEL 2 RESPONSE

The government should require that the wastewater be treated more before being released. The pH is still higher than the river water. The trade-off is it will be more expensive.

LEVEL 1 RESPONSE

The government should require that the wastewater be treated more before being released because it might hurt the environment.

CONNECTIONS TO EVERYDAY LIFE

6. **Rita makes a recipe using a large glass measuring cup that holds up to 3 cups of liquid. Her final dish never turns out quite right. Explain how she could validate the accuracy of her measuring tool.**

   Rita could use a different measuring cup, such as a 1-cup container, and fill it up 3 times to compare it to the amount measured by using the large measuring cup. She could then determine if it is accurately measuring 3 cups.

7. **Suppose you are using a thermometer to track the temperature in your home, but you suspect it is not working. How could you validate its temperature reading?**

   You could compare it to data from your own senses (does the room feel warm or cold), place the thermometer in boiling water to see if it reads 100°C (212°F), place it in a glass of ice water to see if it reads 0°C (32°F), or use it to take your body temperature 37°C (98.6°F).

REFERENCES

Fondriest Environmental, Inc. (2013, November 19). pH of water. Fundamentals of Environmental Measurements. Retrieved from https://www.fondriest.com/environmental-measurements/parameters/water quality/ph/

STUDENT SHEET 2.1 | DATA TABLES | NAME

PART A

TABLE 2.1: OBSERVATIONS

LIQUID	APPEARANCE	ODOR	PREDICTED pH
A. DISTILLED WATER			
B. DRINKING WATER			
C. AMMONIA			
D. VINEGAR			

PART B

TABLE 2.2: TESTING pH WITH RED-CABBAGE JUICE

LIQUID	FINAL COLOR	APPROXIMATE pH RANGE	ACIDIC, BASIC, OR NEUTRAL?
A. DISTILLED WATER			
B. DRINKING WATER			
C. AMMONIA			
D. VINEGAR			
E. CONTROL (CABBAGE JUICE)		*7*	*neutral*

TABLE 2.3 IS AN INFORMATIONAL TABLE FOUND ONLY IN THE STUDENT BOOK.

PART C

TABLE 2.4: TESTING pH WITH pH PAPER

LIQUID	PAPER COLOR AFTER TESTING A LIQUID*	pH	ACIDIC, BASIC, OR NEUTRAL?
A. DISTILLED WATER			
B. DRINKING WATER			
C. AMMONIA			
D. VINEGAR			

*varies based on pH paper used

PART D

TABLE 2.5: TESTING AND COMPARING pH WITH pH PROBES

LIQUID	PREDICTED pH	pH FROM CABBAGE JUICE	pH FROM pH PAPER	pH FROM pH METER
A. DISTILLED WATER				*
B. DRINKING WATER				
C. AMMONIA				
D. VINEGAR				

*not measurable with probe

STUDENT SHEET 2.1 | DATA TABLES | NAME SAMPLE STUDENT RESPONSE

PART A

TABLE 2.1: OBSERVATIONS

LIQUID	APPEARANCE	ODOR	PREDICTED pH
A. DISTILLED WATER	*clear, colorless*	*none*	*7*
B. DRINKING WATER	*clear, colorless*	*none*	*7*
C. AMMONIA	*clear, colorless*	*strong, pool-water smell*	*10*
D. VINEGAR	*clear, colorless*	*sharp, sour*	*4*

PART B

TABLE 2.2: TESTING pH WITH RED-CABBAGE JUICE

LIQUID	FINAL COLOR	APPROXIMATE pH RANGE	ACIDIC, BASIC, OR NEUTRAL?
A. DISTILLED WATER	*violet*	*7*	*neutral*
B. DRINKING WATER	*violet / blue*	*7 - 8*	*neutral / slightly basic*
C. AMMONIA	*green*	*12 - 14*	*basic*
D. VINEGAR	*pink / dark red*	*1 - 3*	*acidic*
E. CONTROL (CABBAGE JUICE)	*purple*	*7*	*neutral*

TABLE 2.3 IS AN INFORMATIONAL TABLE FOUND ONLY IN THE STUDENT BOOK.

PART C

TABLE 2.4: TESTING pH WITH pH PAPER

LIQUID	PAPER COLOR AFTER TESTING A LIQUID*	pH	ACIDIC, BASIC, OR NEUTRAL?
A. DISTILLED WATER	*bright spring green*	*7*	*neutral*
B. DRINKING WATER	*grass green*	*8*	*neutral / slightly basic*
C. AMMONIA	*dark forest green*	*13*	*basic*
D. VINEGAR	*bright orange*	*2*	*acidic*

*varies based on pH paper used

PART D

TABLE 2.5: TESTING AND COMPARING pH WITH pH PROBES

LIQUID	PREDICTED pH	pH FROM CABBAGE JUICE	pH FROM pH PAPER	pH FROM pH METER
A. DISTILLED WATER	*7*	*7*	*7*	*
B. DRINKING WATER	*7*	*7 - 8*	*8*	*8.1*
C. AMMONIA	*10*	*12 - 14*	*13*	*11.2*
D. VINEGAR	*4*	*1 - 3*	*2*	*2.4*

*not measurable with probe

STUDENT SHEET 1.3 | WRITING FRAME: EVIDENCE & TRADE-OFFS | NAME

THERE IS A LOT OF DISCUSSION ABOUT THE ISSUE OF

MY DECISION IS THAT

MY DECISION IS BASED ON THE FOLLOWING EVIDENCE:

FIRST,

SECOND,

THIRD,

THE TRADE-OFF(S)

PEOPLE WHO DISAGREE WITH MY DECISION MIGHT SAY THAT

STUDENT SHEET 1.3 | WRITING FRAME: EVIDENCE & TRADE-OFFS | NAME *SAMPLE STUDENT RESPONSE*

THERE IS A LOT OF DISCUSSION ABOUT THE ISSUE OF

water quality.

MY DECISION IS THAT

the wastewater should be required to be treated more before being released.

MY DECISION IS BASED ON THE FOLLOWING EVIDENCE:

FIRST,

the pH of drinking water is expected to be within a range of 6.5–9, and the company is releasing it at 6.3, which is lower than drinking water standards.

SECOND,

the ideal pH range for aquatic organisms such as snails is higher (over 7).

THIRD,

even though the pH of the water might go up as the water cools, it is still going into the river as being too acidic.

THE TRADE-OFF(S)

is that treating the water will use more energy and cost more money.

PEOPLE WHO DISAGREE WITH MY DECISION MIGHT SAY THAT

the difference in pH from 6.3 to 6.5 is quite small, and the water will be diluted once it is released into the river.

WHEN TO USE THIS SCORING GUIDE:

This Scoring Guide is used when students are making a choice or developing an argument about a socioscientific issue when arguments may include judgments based on nonscientific factors.

WHAT TO LOOK FOR:

- Response uses relevant evidence, concepts, and process skills to compare multiple options in order to make a choice.
- Response takes a position supported by evidence and describes what is given up (traded off) for the chosen option.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 4 **Complete and correct**	The student provides a clear and relevant choice with appropriate and sufficient evidence, including BOTH of the following: • a thorough description of the trade-offs of the decision • reasons why an alternative choice was rejected (if applicable)	**The student's response includes:** • a clear description of their decision about requiring additional water treatment. • a clear, thorough description of at least three pieces of evidence that are relevant to, and support their position, including evidence from the activity (not in the question prompt). • a clear, thorough description of at least one appropriate trade-off.
Level 3 **Almost there**	The student provides a clear and relevant choice with appropriate and sufficient evidence, BUT one or both of the following are insufficient: • the description of the trade-offs • reasons why an alternate choice was rejected (if applicable)	**The student's response includes:** • a clear description of their decision about requiring additional water treatment. • at least three pieces of evidence that are relevant to, and support their position. • at least one appropriate trade-off. • descriptions of evidence and trade-offs may be unclear or insufficient.

LEVEL	GENERAL DESCRIPTION	ITEM-SPECIFIC DESCRIPTION
Level 2 **On the way**	The student provides a clear and relevant choice, BUT the evidence is incomplete.	**The student's response includes:** • a clear description of their decision about requiring additional water treatment. • at least one piece of evidence that is relevant to their decision. **And may include:** • at least one trade-off **However, evidence is less than three pieces and/or trade-off is missing or unclear.**
Level 1 **Getting started**	The student provides a clear and relevant choice BUT provides evidence that is subjective, inaccurate, or irrelevant.	**The student's response includes:** • a clear description of their decision about requiring additional water treatment. **However, evidence is subjective, inaccurate, or irrelevant and/or trade-off is missing or unclear.**
Level 0	The student's response is missing, illegible, or irrelevant.	
X	The student had no opportunity to respond.	