NAVIGATING™ NUCLEAR
Energizing Our World

Project Starters

Topic

Decay Detectives: Art Forgery or Masterpiece?

OBJECTIVES

Students will:

- Investigate and calculate radioactive decay, half-life, and radiocarbon dating.
- Research the process of using microscale radiocarbon dating to determine the age of paintings.
- Analyze mock radiocarbon data to make decisions about potential forgeries.

Overview

In this activity, students will investigate radioactive decay, half-life, and the process of radiocarbon dating. Then, students will research the process of using microscale radiocarbon dating to determine the age of paintings through accelerator mass spectrometry (AMS), which uses minimal sample sizes to evaluate the age of paintings to detect possible forgeries. Finally, students will become forensic scientists, using mock data to decide whether a series of paintings are likely genuine, likely forgeries, or definite forgeries by analyzing the radiocarbon data from the canvas and paint layers to see if the readings match what would be expected based on the date of the painting. As an extension, students will complete a radiometric dating lab in which they simulate the radioactive decay of elements and some of the principles of radiometric dating.

Grade level

9–12

Real World Science Topics

- Dating artifacts
- Nuclear chemistry
- Half-life
- Mass spectrometry

Next Generation Science Standards (NGSS)

HS-PS1-8

Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

Science and Engineering Practices

Using Mathematics and Computational Thinking

- Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.
- Use mathematical representations of phenomena to support claims. (HS-PS1-7)

Disciplinary Core Ideas

PS1.C: Nuclear Processes

- Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process. (HSPS1-8)

Crosscutting Concepts

Energy and Matter

- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. (HS-PS1-8)

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable. (HS-PS1-6)

Time Needed

1–2 Hrs.

Background Information

The decay of radioactive materials is a random process, similar to flipping a coin or rolling a die. At any instant, there is a chance that an atom will decay, but there is also a chance it will remain the same. The rate at which radioactive materials decay is measured by their "half-life," which describes how long, on average, it takes for one-half of the original radioactive atoms to decay. Scientists use this understanding of radioactive decay to undertake radiocarbon dating, a method for determining the age of an object containing organic material by using the properties of radiocarbon (C-14), a radioactive isotope of carbon. By measuring the radioactive decay in a sample of bone or other organic material (such as wood, plant fibers, or cloth), archaeologists can estimate the age of that material.

Similarly, forensic scientists have used radiocarbon dating for decades to test the age of the organic materials in the canvas and wooden supports of paintings suspected of being art forgeries. If the canvas doesn't match the age in the painting's signature, then it is a forgery. However, crafty art forgers have been known to reuse antique canvases to fool experts trying to spot a fake. In these cases, scientists might examine small samples of paint from the surface of the painting to try to detect chemicals that would be consistent with historically accurate paints. Yet, because of concerns of damaging an authentic painting, taking samples of the paint itself was considered too invasive, or the results of these chemical tests might be inconclusive. Recent advances in radiocarbon dating are helping forensic scientists detect more expertly forged paintings. With the advent of accelerator mass spectrometry (AMS), the amount of carbon necessary for obtaining a radiocarbon date has been significantly reduced. Scientists are now able to take very small samples (micrograms) versus the 10 grams previously required for radiocarbon dating of organic material (binder) contained within the paint layer to determine if the age of the paint layer, as well as the canvas, match the painting's date.

Key Vocabulary

- **Half-life:** the time taken for the isotope's mass to decrease to half its original value.
- **Radiocarbon dating:** (also referred to as carbon dating or carbon-14 dating) is a method for determining the age of an object containing organic material by using the properties of radiocarbon (C-14), a radioactive isotope of carbon.
- **Accelerator mass spectrometry (AMS):** an analytical technique that accelerates ions to extraordinarily high kinetic energies before mass analysis. The special strength of AMS among the mass spectrometric methods is its power to separate a rare isotope from an abundant neighboring mass ("abundance sensitivity", e.g. C–14 from C–12).
- **Forgery:** the action of forging or producing a copy of a document, signature, banknote, or work of art.

Materials & Equipment

- Copies of the 3-2-1 chart (one per student)
- Computers or other devices connected to the internet
- Copies of the *Micro-scale Radiocarbon Jigsaw* capture sheet (one per student)
- Copies of the *Art Forgery Lab* sheet (one per student)

Procedure

1. **Warm-Up Activity:** As an activator and to establish the context for the lesson show the video, "How Carbon Dating Works" (approximately 4 minutes). https://youtu.be/Kcuz1JiMk9k

   As students watch the video, ask them to complete the 3-2-1 chart. Afterwards, students will pair up with a partner and exchange charts. After they've had a chance to look at each other's charts, call on students using equitable calling strategies to share with the rest of the class.

   Key points to emphasize from the video include:

   - Carbon dating (or carbon-14 dating) is a form of radiometric dating and it measures the decay of a certain type of atom found in a once living organism to determine when it was last alive.
   - Bombardment by cosmic rays in the upper atmosphere of the Earth causes stable nitrogen-14 atoms to decay into carbon-14 atoms, which are radioactive. Stable carbon-12 atoms are also present but in greater abundance.

- The ratio of carbon-12 to carbon-14 found in living things on Earth is pretty much the same as what is present in the upper atmosphere, making it predictable.
- Willard Libby determined that carbon-14 decays at a predictable rate, and he is credited with inventing carbon-14 dating.
- Radioactive particles have a half-life, which is the amount of time it takes for the number of radioactive particles in a sample to decrease by half. Carbon-14 has a half-life of 5,730 years. After two half-lives (11,460 years), there will be a quarter of the amount of carbon-14 that was originally present.
- One of the limitations of carbon dating is that if you go far enough back in time, all the carbon-14 atoms would have decayed and you don't know whether this took place a day before or 100,000 years before. The limit with carbon dating is about 50,000 years.

2. **Micro-scale Radiocarbon Jigsaw:** Next, students will research a new micro-scale radiocarbon method that determines the age of paintings through accelerator mass spectrometry (AMS), which uses minimal sample sizes to evaluate the age of paintings to detect possible forgeries. Break students into four groups of roughly equal size. Each group will become "experts" on one of the following resources:
   - Accelerator Mass Spectrometry (AMS) Dating: https://www.radiocarbon.com/accelerator-mass-spectrometry.htm
   - Uncovering modern paint forgeries by radiocarbon dating: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6613091/
   - Radiocarbon Dating May Help Uncover Art Forgeries: https://www.forbes.com/sites/samanthabaker1/2019/06/25/radiocarbon-dating-may-help-uncover-art-forgeries/#6a3f1cdf71e6
   - Exposing modern forgers—The chemical refinement of radiocarbon dating: https://www.sciencedaily.com/releases/2019/06/190604131221.htm

   Instruct students to first read their article independently (online, or print a class set of articles—six or more copies of each, depending on class size). Give students five to seven minutes to read. Students then will discuss the article briefly with their group members (3–5 minutes) and complete a jigsaw chart for their article as a group. Students then rotate to a second Jigsaw group, ensuring that there is at least one representative of each article to discuss/exchange information and to complete the other sections of their Jigsaw capture sheet (7–10 minutes).

   Students should focus on the following key aspects:
   - How does radiocarbon dating help detect art forgeries?
   - How have skillful forgers avoided detection?
   - How is Accelerator Mass Spectrometry (AMS) an improvement on previous techniques?

   By the end, each student should have completed all four jigsaw charts.

3. **You Be the Forensic Scientist Activity:** Next, tell students they will become forensic scientists as they use mock data to decide whether a series of paintings are likely genuine, likely forgeries, or definite forgeries by analyzing radiocarbon data.

   Pass out the Art Forgery Lab sheet. Students will use the carbon-14 dating calculator available at the following link: https://www.math.upenn.edu/~deturck/m170/c14/carbdate.html

   They will determine whether the percentage of C-14 remaining on canvas and binder match what would be expected in a painting of this age. Students will encounter the following possibilities:
   - If the percentage of C-14 in both the binder and canvas match, the painting is likely genuine.

- If only 1 percent of C-14 matches (either binder or canvas), then the painting is likely a forgery.
- If neither percentage of C-14 matches, then the painting is definitely a forgery.

In cases of possible or definite forgery, instruct students to use the carbon-14 calculator to determine the year of the forgery.

Students should complete the table with all of the relevant information.

Review the results as a class (key below) and if time permits, move on to the extension activity.

1842	97.7%	97.8%	**Genuine**	**n/a**
1619	96.4%	97.9%	**Likely forgery (based on binder age)**	**1839 +/- 5 yrs.***
1735	96.6%	96.7%	**Genuine**	**n/a**
1809	97.5%	99.1%	**Likely forgery (based on binder age)**	**1939 +/- 5 yrs.***
1574	97.6%	97.7%	**Definite forgery (both binder and canvas do not match)**	**1829 +/- 5 yrs.** (based on binder)**

*Using 2019 as the current year.

Extension Activity

As an extension, students will complete a radiometric dating lab in which they simulate the radioactive decay of elements and observe some of the principles of radiometric dating.

http://faculty.ccbcmd.edu/courses/ersc101webct/unit1/dating_lab.html

After students collect data in the lab activity and read about the assumptions of radiometric dating, they will answer a series of critical-thinking questions, which include graphical analysis and problem-solving.

Name: _____

STUDENT HANDOUT

Student Resource: 3-2-1 Chart

3

Name **three** things you learned about carbon dating from the video.

_____

_____

_____

2

List **two** things about carbon dating you want to learn more about.

_____

_____

1

Ask **one** question about carbon dating.

_____

Name: _____

STUDENT HANDOUT

Micro-scale Radiocarbon Jigsaw

Directions: Read your assigned article independently (5–7 minutes); then discuss the article with your first Jigsaw group (3–5 minutes). Work together to complete the jigsaw chart below for your article (write down your answers on your own paper). Then, rotate to your second Jigsaw group, ensuring that there is at least one representative for each article to discuss/exchange information and to complete the other sections of the Jigsaw capture sheet (7–10 minutes). *Note: Some information will be repeated in the articles but try to tease out unique details.*

Accelerator Mass Spectrometry (AMS) Dating:		
How does radiocarbon dating help detect art forgeries?	How have skillful forgers avoided detection?	How is Accelerator Mass Spectrometry (AMS) an improvement on previous techniques?
Uncovering modern paint forgeries by radiocarbon dating:		
How does radiocarbon dating help detect art forgeries?	How have skillful forgers avoided detection?	How is Accelerator Mass Spectrometry (AMS) an improvement on previous techniques?
Carbon Dating May Help Uncover Art Forgeries:		
w does radiocarbon dating help detect art forgeries?	How have skillful forgers avoided detection?	How is Accelerator Mass Spectrometry (AMS) an improvement on previous techniques?
Exposing modern forgers—The chemical refinement of radiocarbon dating:		
How does radiocarbon dating help detect art forgeries?	How have skillful forgers avoided detection?	How is Accelerator Mass Spectrometry (AMS) an improvement on previous techniques?

Name: _____

STUDENT HANDOUT

Art Forgery Lab Sheet

Directions: Use the Carbon 14 Dating Calculator at: https://www.math.upenn.edu/~deturck/m170/c14/carbdate.html to determine whether the percentage of C-14 remaining on a particular canvas and in the binder (in the paint layer) match what would be expected in a painting of this age. *Note: You must first subtract the **year of the painting** from the **current year** to get the number of "Years" for the calculation.*

You will encounter the following possibilities:

- If the percentage of C-14 in both the binder and canvas match, the painting is likely genuine.
- If only the percentages of C-14 in the canvas matches, then the painting is likely a forgery.
- If neither percentage of C-14 matches, then the painting is definitely a forgery.

Remember, to be considered a match, the date indicated by the percentages of C-14 in both the canvas and binder should be within about 10–20 years before the date of the signature and should not be at any point later than the date of the signature because that would mean those items date to after the painting was supposedly made.

In cases of possible or definite forgery, use the carbon-14 calculator to estimate the year of the forgery by using the % of C-14 in the binder. Complete the table.

Painting Date (in signature)	% C-14 in Canvas	% C-14 in Binder (Paint)	Genuine, Likely Forgery, or Definite Forgery?	Year of Forgery (if applicable)
1842	97.7%	97.8%		
1619	96.4%	97.9%		
1735	96.6%	96.7%		
1809	97.5%	99.1%		
1574	97.6%	97.7%		