COLORS OF NATURE / KIT 2
CHEMISTRY AND ART

HOW DOES THE CHEMISTRY OF COLOR HELP US UNDERSTAND THE WORLD AROUND US?

The Colors of Nature Kits are designed to help students explore the core question: *how do art and science help us understand the world around us?* Through a series of investigations students become familiar with the core practices of art and science, and develop scientific and artistic habits of mind that empower them to engage in self-directed inquiry through the generation and evaluation of ideas. Kit 2 frames this line of inquiry through the perspective of chemistry: the study of matter and the changes it can undergo.

A STEAM APPROACH TO EDUCATION (Science, Technology, Engineering, Art, Math)

STEAM is an educational philosophy that seeks to balance the development of divergent and convergent thinking by integrating the arts with traditional STEM fields (Science, Technology, Engineering, Math). In the STEAM approach to learning, students engage in projects and experiments that reflect the transdisciplinary nature of real-world problem solving. Rather than focusing on the delivery and memorization of content as isolated facts or repetition of rote procedures, STEAM seeks to develop scientific and artistic habits of mind and the confidence to engage in self-directed inquiry by familiarizing students with the core practices of art and science in an open and exploratory environment. The STEAM investigations in this kit are designed to foster creative inquiry by promoting individual agency and establishing meaningful connections to students' own lives.

INVESTIGATING THE CHEMISTRY OF COLOR

In this series of investigations we will explore the relationship between chemistry and color, and how one informs the other. Pigments are the colorful compounds that lend their hues to most of the world around us. Using chromatography, we will separate the individual pigments in spinach leaves and magic markers to better understand what their colors are made of. Then, using acids and bases, we will alter the chemical structure of the pigment in red cabbage to learn how chemistry can be used to manipulate color as well as what color can tell us about chemistry. Finally, we will explore how sunlight can initiate a chemical reaction in cyanotype pigments and how we can harness that reaction to create photographic images.

INVESTIGATION 1 / Chemical Separation:
Chromatography

What is color made of?

INVESTIGATION 2 / Acid-Base Reaction:
Red Cabbage Painting

How can we manipulate color with chemistry?

INVESTIGATION 3/ Photochemical Reaction:
Cyanotypes

How can light affect the chemistry of color?

WHAT IS CHEMISTRY?

Chemistry is the study of matter and the changes it can undergo. Matter refers to anything with mass and volume, the physical “stuff” in the universe. All matter is made up of either **chemical elements** (like hydrogen and oxygen) or **compounds** (like H_2O), which are chemically bonded mixtures of elements.

The smallest particle of a chemical element or compound that maintains the same chemical properties is called a **molecule**. Molecules can be all shapes and sizes, and can be as small as one atom, like helium. The oxygen we breathe, O_2, is made up of two chemically bonded oxygen atoms. When three oxygen atoms bond together they form a compound we call ozone. Water, H_2O, is a compound molecule made of two hydrogen atoms and one oxygen atom.

If the chemical bonds of a molecule are broken, atoms can rearrange and recombine with other atoms, creating new molecular structures. We call this process a **chemical reaction**. The substances that go into a chemical reaction are called reactants and the substances that form as a result are called products. Chemical reactions are happening in and around us all of the time, from inside our cells to stars in faraway galaxies.

Right: A student testing plants, soil, and other sources in the vicinity of the classroom for useful pigments.

ART / SCIENCE OVERLAP in CHEMISTRY

Art and science are intricately intertwined throughout human history, and this overlap is perhaps nowhere more apparent than in the field of **chemistry**. Our technical and cultural innovations stem from our ability to identify, separate, and manipulate the raw materials in our environment with ever-greater complexity and precision. Wherever you are right now, look around. Brilliant color is everywhere: in the clothes we wear, the structures that shelter us, even the foods we eat. Our understanding of chemistry has allowed us to create a world with an unprecedented abundance of color.

THE CHEMISTRY OF COLOR

Long before anyone in a lab coat synthesized colorful concoctions in beakers and tubes, humans harnessed the power of chemical reactions to manipulate the world around them. We used fire (a chemical reaction between a fuel and an oxidant called combustion) to cook, provide heat, and bring light to the darkness. We used fermentation (a reaction that converts sugar to acids, gases, or alcohol) to preserve foods and to make beer, bread, wine and cheese. We learned to use fire to transform earth into pottery and glass, to extract metals from the ores in which they occurred, and to recombine them as alloys. Each discovery ushered in major technological and cultural shifts, and as our knowledge of chemical reactions advanced, so did the color palette available to us for our art and adornment.

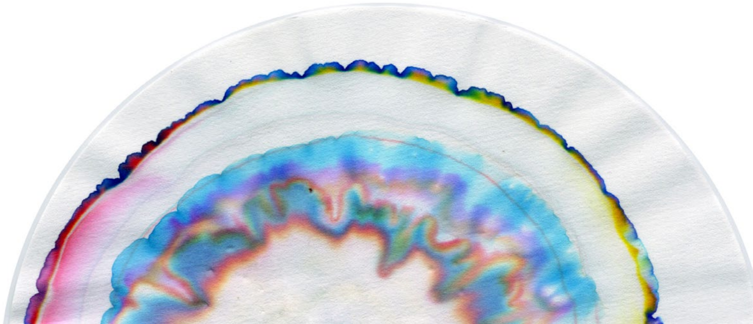
Our insatiable attraction to bright colors seems to predate the emergence of the modern human species. Archaeological evidence indicates that as long as 400,000 years ago, early hominids such as Neanderthals collected unusually bright mineral fragments containing red iron oxides, and even transported these choice pigments long distances from their origins. Although their exact use is unknown, we can speculate that they were appreciated for their saturated colors.

The earliest examples we have of painting date to over 40,000 years ago, when humans began to create symbolic imagery on cave walls. These prehistoric cave paintings, found across the globe from Europe to Southeast Asia to Africa, all have a similar color palette of rusty reds, black, and white. Why? Because these are the stable pigments that occur most abundantly across the earth. Iron oxides (think of rust) in rocks and soils provided a range of colors from yellows to reds. Charcoal from burnt wood or bones provided a rich carbon black, and kaolin clay or chalk (calcium carbonate) deposits provided bright white pigments.

As technology advanced and we became more adept at identifying, separating and manipulating the materials in the world around us through chemistry, our color palettes expanded with the development of new pigments and dyes. In turn, our desire for brilliant colors drove experimentation and innovation. Colorfast blue and purple pigments are rare in nature and were highly sought after. Without understanding chemistry the way we do today, some ancient civilizations nonetheless discovered how to synthesize prized colors from available materials, and guarded their recipes closely.

The Egyptians discovered that by melting quartz, lime, and copper together, and pulverizing the resulting glass, they could make a bright blue pigment. The Indus Valley Civilization developed a deep blue colorfast dye by fermenting the leaves of the indigo plant and mixing it with lye, and the Phoenicians developed a purple dye from the photosensitive secretions of a sea-snail boiled for days in a lead vat. Cloth from these labor-intensive processes could cost more than its weight in gold, and was often restricted to exclusive use by royalty.

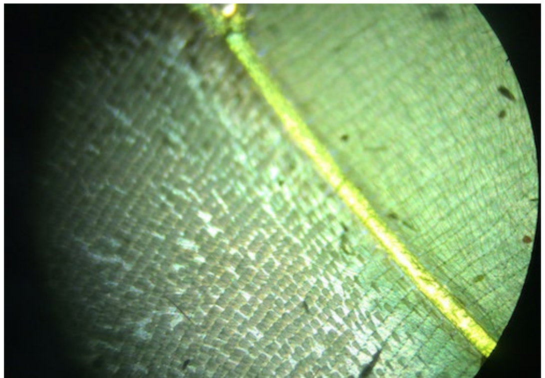
These ancient recipes remained the primary source for some colors for millennia, until modern chemistry revealed the secrets of chemical color. In 1856 a chemist who was attempting to synthesize quinine, a malaria treatment, accidentally synthesized the first modern dye, a brilliant purple called mauvine. Only a few years later, another chemist synthesized indigo, and the era of industrial synthetic pigments opened up a vibrant new world of accessible color across the visible spectrum.



INSTRUCTIONAL METHOD

We advocate for a STEAM approach that quiets the inner negative voice, focuses on open outcomes, and values student ideas and expression. Foundational to our approach are practices that promote identification with science and art, including the use of real science and art tools; connect science and art to everyday life; and offer students the chance to participate in authentic science and art practices.

- **Give students choices when possible. A sense of agency can increase identification with science.**
- **Accept student responses as value-neutral.**
- **Ask questions and encourage discussion and reflection.**
- **Connect activities to everyday practices and student-relevant ideas.**



GUIDING DISCUSSION AND REFLECTION

It is important to establish an environment that encourages imaginative speculation, or thinking outside the box. If students are conditioned to "take things seriously" during classtime, they might not be comfortable offering the creative or humorous answers that are often generated by divergent thinking.

The instructor should continue asking questions to lead the discussion beyond the point where students offer answers that they believe are "correct" or what they think the instructor expects to hear. This can be facilitated by the instructor's willingness to contribute their own playful ideas and follow up with questions that solicit deeper analysis:

What do this fly's eyes remind you of?

They remind me of a discoball!

What about them is like a discoball?

What does a discoball do to light?

What do you think the fly's eyes do to light?

How might this be useful for the fly?

ASKING QUESTIONS TO DEEPEN ENGAGEMENT

Each investigation in this kit provides:

A central question to focus the investigation, repeated in the header of each page.

Specific questions integrated with the procedural steps of the activity to prompt the discussion, *shown in italics for quick reference.*

Throughout the activity, the instructor should use open questions to guide observation, encourage experimentation, and prompt reflection.

Questions should aim to:

Expand upon an idea:
what else could you do with this? could this be for? could this mean?

Draw attention to specific details:
what do you see? what texture? color? pattern?
what is different/similar between this and that?

Encourage synthesis with existing knowledge:
what does this remind you of? where have you seen something like this before?
what about this is different than where you saw something similar before?

ART / SCIENCE OVERLAP

Both science and art seek to broaden our understanding of the world around us. Although art and science are often thought of as separate ways of knowing, they are similar in many important ways in principles and practice. Driven by curiosity, creativity and technique, both disciplines contribute new experiences, ideas, and technologies to society and create the foundation of knowledge from which future innovations emerge. The core practices of art and science reveal significant overlap as well: observing, questioning, experimenting, analyzing, and communicating are the means by which both disciplines generate and distribute new ideas and technologies.

CORE PRACTICES of ART and SCIENCE

Observing

Experimenting

Questioning

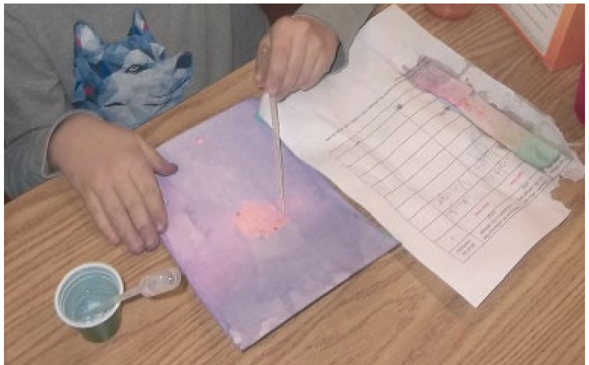
Analyzing

Describing

Communicating

ENGAGEMENT IN SCIENCE PRACTICE

Young children engage naturally in core science practices. They make observations and test and revise their predictions as they seek to understand how the world around them works (how high can I stack these blocks before they tumble?). But when science is presented in the classroom as isolated facts to be memorized, or procedural steps to copy, students can lose sight of their own capacity to question the world around them, test their ideas, and share their discoveries. Many students, especially girls and people from non-dominant groups, start to view science as rote, passionless, and uncreative. Students who have difficulty memorizing and repeating facts, or making connections to complex systems that don't feel relevant to their daily lives begin to disengage from science. Again, these STEAM investigations should emphasize developing familiarity with the practice and tools of scientific inquiry, rather than on memorizing content or achieving specific results.



ENGAGEMENT IN ART PRACTICE

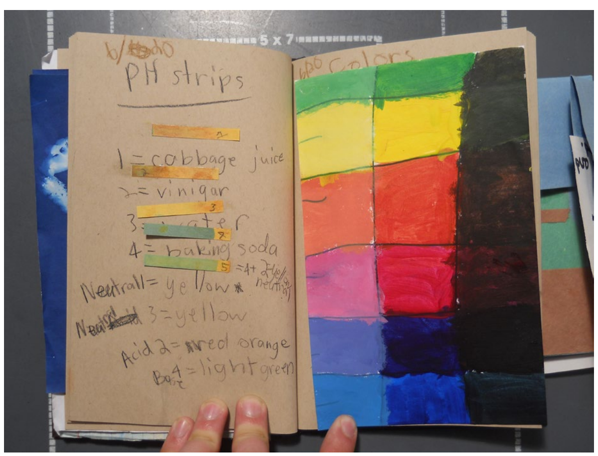
Similarly, young children almost universally engage in art making. They progress from simple scribbles as they learn to handle and control their mark-making tools to the development of symbols that represent their understanding of the world. As the complexity of these graphical symbols increases, children begin to aim for realism (of proportion, form, lighting) in their representation. Around age 9, as social awareness increases, children begin to shift their focus from the expressive pleasure of making art to the results of their work, especially in comparison to the work of their peers. Between age 10 and 13, children decide whether or not they are good at art (as opposed to whether or not they enjoy making art), and it is in this stage of development that many children cease to engage in art-making, believing they do not have the talent to produce good (realistic) results. These beliefs are often reinforced by peers and adults who similarly value conventions of realism in western art. When an adult claims "they can't draw," we automatically understand them to mean that they can't draw realistically, not that they can't move a pen across a piece of paper. With continued practice and instruction, nearly everyone can develop skills of realistic representation. Nevertheless, the following STEAM investigations should remain focused on the act of art making itself: an awareness of the opportunities that present themselves and the creative choices that are made in the course of artistic practice. The results of each activity are useful as a record of the process, but the emphasis should be placed on the importance of observing, experimenting, and reflecting on the activity itself.

INTRODUCTION / NOTEBOOK EXTENSION

NOTEBOOK EXTENSION

Keeping a notebook is a common practice in both art and science. The notebook is a place to keep track of ideas, observations, measurements, sketches and other information relevant to the ideas the practitioner is exploring. It is a space that allows for informal musings and reflections alongside notes and data recorded for later reference. Each investigation in the Colors of Nature Kits includes suggestions on how to incorporate the notebook into the lesson.

Notebooks can be incorporated into numerous other classroom activities beyond these investigations, providing a private space for students to reflect on what they are learning and develop their ideas outside of the normal constraints of classroom assignments.



MATERIALS

• Blank student notebooks

• Writing/ drawing tools (pens, pencils, etc.)

• Glue stick

INTRODUCTION

Discuss with students the various reasons why artists and scientists might keep notebooks and how it helps them study the world around them.

Why do artists and scientists keep notebooks?

Some examples include, but are not limited to:

- observe a subject more closely
- record observations when other methods of recording are not possible or available at the time
- capture additional information such as measurements, notes, other observations
- keep a record of what was done, how data was collected
- think through and work out ideas and designs on paper before trying in real life

PREPARE NOTEBOOKS FOR USE

Discuss with students what information might be useful to include in their notebook, to assist with identification and use as a reference of their observations. At the very least, have students write their name on the inside cover, so missplaced notebooks can be returned to their owner when found.

What information might be important to include in the notebook?

Some examples include, but are not limited to:

- name
- contact information
- page numbers
- page titles
- table of contents
- dates of entries or observations
- measurements
- photos or other materials that can be glued into the book.

COLORS OF NATURE / KIT 2

HOW DOES THE CHEMISTRY OF COLOR HELP US UNDERSTAND THE WORLD AROUND US?

INVESTIGATION 1 / WHAT IS COLOR MADE OF?

CHROMATOGRAPHY

OVERVIEW

Using chromatography, students will separate the pigments in spinach leaves and felt tip markers. Students will then use what they have learned about pigment separation to experiment with different art outcomes, and purposely design for a desired outcome for an abstract artwork. This investigation demonstrates that matter is made up of tiny particles with unique chemical characteristics, making it possible to separate and identify individual components of a mixture. One of these characteristics is color: pigments are molecules that reflect and absorb specific wavelengths of visible light and are responsible for most (but not all) of the colors we see in the world around us.

LEARNING OBJECTIVES

Students will be able to discuss and demonstrate examples of how:

- *Many of the colors that we see in the world around us are the result of molecules, too small to be seen individually, that absorb and reflect specific wavelengths of light.*
- *Pigments can be separated from the material they color using techniques like chromatography.*
- *Chromatography can be used to explore the colorful pigments in art materials, and to experiment with developing new art making techniques and approaches.*

GRADES:
4-6

TIME REQUIREMENT:
60 minutes

SCIENCE STANDARDS (NGSS):

Performance Expectation:

5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.

[Clarification Statement: Examples of evidence could include adding air to expand a basketball, compressing air in a syringe, dissolving sugar in water, and evaporating salt water.]

5-PS1-3. Make observations and measurements to identify materials based on their properties.

[Clarification Statement: Examples of materials to be identified could include baking soda and other powders, metals, minerals, and liquids. Examples of properties could include color, hardness, reflectivity, electrical conductivity, thermal conductivity, response to magnetic forces, and solubility; density is not intended as an identifiable property.]

Crosscutting Concepts:

Influence of Science, Engineering, and Technology on Society and the Natural World:

The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions.

ART STANDARDS (NCCAS):

VA:Cr1.2.5a Identify and demonstrate diverse methods of artistic investigation to choose an approach for beginning a work of art.

VA:Cr2.1.4 Explore and invent art-making techniques and approaches.

VA:Cr2.1.6 Demonstrate openness in trying new ideas, materials, methods, and approaches in making works of art and design.

TEACHER BACKGROUND

This investigation is designed to introduce students to the particles that are responsible for most of the colors we see in the world around us. Too small to be seen individually by the naked eye, these particles, called pigments, absorb specific wavelengths of light while reflecting others back to our eye. Pigments are responsible for the green of leaves, the pink of flamingos, the colors of the clothes we wear, and the brushstrokes a painter puts on canvas.

It is important to note that not *all* of the colors we see around us come from pigments. Some colors are the result of other optical phenomena, such as scattering or structural color. For example, there is no blue pigment in the sky (the color is a result of Earth's atmosphere interfering with radiation coming from the sun). A pigment can be extracted from the substance it colors, and will still be colorful. Today we will use a simple chemical separation technique, chromatography, to investigate the individual pigments that make up the color of spinach leaves and felt-tipped markers. Our ability to separate and identify individual chemical components in the world around us gives us insight into their function, and is the first step in learning how to change them through chemistry.

INSTRUCTIONAL APPROACH

At the heart of a STEAM approach are practices that encourage close observation and open experimentation. The first part of the lesson offers a structured approach, in which students can practice observational skills, while the second part offers a chance for students to engage in open experimentation of art outcomes associated with pigment separation. Students then use that knowledge to design original artwork.

The instructor should guide the students through questions and prompts that encourage:

- *observation of the materials and their interactions*
- *classification of different materials and their properties*
- *analysis and discussion of results*
- *discussion of how artists and scientists use chemistry in their work*

Accept all student answers as value neutral.

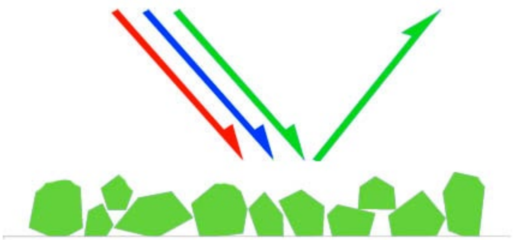
ART BACKGROUND

Pigments have provided us with a means of symbolic expression since our emergence as a species. Prehistoric art from archaeological sites around the world all exhibit a familiar color palette of reds, blacks and whites. These pigments are the most abundantly available of the naturally occurring stable pigments, meaning they do not easily fade or degrade over time.
As civilizations evolved and technologies advanced, other mineral pigments were discovered and traded across vast distances: greens from copper, and blues from lapis lazuli. Although minerals often provided the most stable pigments, plants and animals were used as pigment sources as well. Indigo blue came from the fermented indigo plant, reds from the madder plant, purple from the murex sea snail, and red from crushed cochineal beetle.

The expanding spectrum of pigments available to artists and artisans throughout history coincides with humanity's technical and cultural innovations, from the development of new tools to the division and specialization of labor and the establishment of far-flung trade routes. In fact, synthetic pigments resulting from chemical reactions were discovered long before humans understood the fundamental chemistry involved. Careful observation of matter and the changes it undergoes when exposed to heat or light, or when mixed with other substances, allowed artists and artisans to manipulate chemical compounds, creating new pigments and dyes with desirable properties that did not occur naturally.

SCIENCE BACKGROUND

A **pigment** appears a certain color because it reflects some wavelengths of the **visible spectrum** while absorbing others. For example, the chemical properties of a green pigment cause it to absorb many of the wavelengths in white light except green, which is then reflected back to our eye.



Chlorophylls are the most abundant pigments on earth, creating energy for plants through photosynthesis by absorbing many of the visible wavelengths of light except in the green part of the spectrum, giving most vegetation its familiar color.

In response to the abundance of this green pigment in our environment, the human eye has evolved to be especially sensitive to green light. We can distinguish between tiny differences in shades of green, more so than any other color. This is why night vision goggles are designed to produce a green-hued image.

CHROMATOGRAPHY

Chromatography is a method used by scientists to separate mixtures into their individual components. In chemistry, a mixture refers to a combination of substances that are not chemically bonded to each other, and can be separated by taking advantage of the distinct chemical properties of its components.

In chromatography, the mixture (called the mobile phase) is passed through a medium (called the stationary phase) in which different components travel at different rates due to their preferential attraction towards the material in the mobile or stationary phase. The name comes from the Greek words for "color" and "writing," although the process was developed in 1903 by a Russian botanist in order to study the pigments that make up the colors we observe in plant leaves.

PLANT PIGMENTS

Today we will use filter paper as the stationary phase, and solvents (water and isopropyl alcohol) as the mobile phase to separate the pigments in spinach leaves and black felt tipped markers. When we submerge the end of a hanging strip of filter paper into the solvent containing a pigment mixture, we will see the solution wick up the filter paper due to capillary action. The solvent is also carrying the mixture of pigments. Some pigments are more attracted to the paper than they are to the solvent, and vice versa. Because each pigment has unique chemical properties that determine its affinity for the paper or the solvent, the pigments travel at different rates, separating into bands.

Spinach leaves contain four pigments:

- chlorophyll a (blue green)
- chlorophyll b (yellow-green)
- carotene (orange)
- xanthophyll (yellow)

The carotenes and xanthophylls are responsible for the oranges and yellows we see in autumn leaves after plants halt chlorophyll production in preparation for the winter.

Left: leaf pigment chromatogram of kale, showing the banded separations of the chlorophylls, carotenes, and xanthophyll.

KIT MATERIALS

- **15cm filter paper** (can substitute white coffee filters) cut into 1.5" strips *(at least 2 per student)*
- **Clear 12-oz. cups or jars** *(2 per student)*
- **Isopropyl (rubbing) alcohol** *(2 tbsp per student)*
- **Mortar and pestle** *(1 per group of 2-3 students)*
- **3ml Pipettes** *(1 per group of 2-3 students)*
- **Various colors of washable felt tip markers** *(at least 2 per student, students can share colors)*
- **1 roll clear tape** (like Scotch tape)

ADDITIONAL SUPPLIES

- **Spinach leaves** (or arugula, or kale or any other dark leafy green you can find) *(For spinach, an 8oz bag is plenty; each student needs about 5 leaves to crush)*
- **Other leaves or flowers**, berries, fruit/ vegetables collected in vicinity of classroom *(aim for about a tablespoon of compacted material)*
- **Pencils** *(1 per student)*
- **Scissors** *(1 pair for prep)*

SETUP *10 minutes*

1. Protect working area

This is not an especially messy project, but you may want to use paper or plastic coverings on tables to minimize cleanup from any spills that might occur.

2. Cut paper filters into 1.5" strips

This can also be done as a first step by students, where appropriate.

3. Prepare work stations

Distribute spinach leaves, filter paper strips, jars or cups and pipettes to students. Distribute mortars and pestles to groups of 2-4 students to share.

INTRODUCTION: WHAT IS COLOR MADE OF?

10 minutes

1. Engage the students in the lesson by inviting them to consider what art looked like long ago, when pigments were not readily available from the store. Show students ancient art examples:

- *Cueva de Manos, Argentina (over 9,000 yrs ago)*
- *Egyptian tomb painting (3,300 yrs ago)*
- *Yulin Cave painting, China (1000 years ago)*

Ask students:

-what colors do you see?

-where might the artists have sourced those colors, since they couldn't buy them from the store?

Collect answers on the board. Prompt students to think of plants/minerals/animals as possible sources, if they do not think of this on their own. Share real examples given from art background section if desired.

2. Ask students to think of their favorite color and then identify something in the room that is that color. Have students take a minute to write down their chosen object, its color, and their ideas about:

-what gives my object its specific color?

-where did that color come from?

3. Ask students to imagine themselves as artists a thousand years ago. If they wanted to develop a paint in their favorite color:

-where might they source that color?
-how would they turn it into paint?
-how might that color be made by people today?

4. Now, show students a spinach leaf, a blue felt tipped marker, and something else colorful in the classroom (like a shirt) and ask students to identify the color of each. Then ask students to share their ideas about:

-what makes the spinach leaf green? The marker blue, the shirt red?

Accept all answers neutrally and write them on the board.

CHROMATOGRAPHY PART I: PLANT LEAF CHROMATOGRAMS

10 minutes to set up, 30 minutes for separation. Part II can be done during the waiting period

1. Let students know that they will be learning a technique that will allow them to take apart the spinach leaves and learn more about what gives them their color.

2. Demonstrate using the mortar and pestle to pulverize a few spinach leaves. While one student in the group is using the shared mortar and pestle, the other students can be setting up their cups/jars and filter paper.

3. Have students write their name in pencil on one end of the filter paper strip and tape that end to a pencil so that it hangs about ¼" above the bottom of the cup.

4. As each student finishes mashing their spinach leaves, they can add them to the bottom of their cup and position the pencil across the top of the cup so that the filter paper dangles vertically.

Set up for plant leaf chromatogram.

PLANT LEAF CHROMATOGRAMS ctd.

5. Using pipettes, have students carefully transfer rubbing alcohol from the container into the bottom of their cup until it covers the spinach pulp and just touches the bottom of the filter paper.

SAFETY NOTE: rubbing alcohol is flammable. Assess the environment to make sure no heat, sparks, or flames are present before proceeding. Let students know that while rubbing alcohol is often used to disinfect cuts and scrapes, it is a strong chemical and should be handled with care in a calm environment.

6. Almost immediately the filter paper will begin wicking the alcohol and spinach solution upwards, although it will take about 30 minutes for the pigments to separate. Direct student attention towards this process.

7. Ask students to share with the group:

-what changes do you observe happening? (filter paper wicking alcohol and pigments upwards)

-why do you think this is happening?

-have you observed something like this anywhere else? (paper towels, sponges)

-what do you predict the strip will look like if we allow it to continue?

8. This is a good time to introduce terminology, including **chromatography** (from Greek words chroma + graph = “color writing”): a technique used to separate parts of a mixture and pigment (a tiny molecule, too small to be seen by the naked eye, that absorbs some wavelengths of light while reflecting others). C**hlorophyll** is the type of pigment that makes many plants green. Note that it is also responsible for photosynthesis.

9. Set aside the plant leaf chromatography while it separates. In the meantime, we will use the same chromatography process to create art with felt tip markers.

Left:
The solvent immediately begins wicking up the filter paper, carrying the leaf pigments with it. Here they are beginning to separate into distinct bands.

PART II: INK CHROMATOGRAMS

20 minutes while waiting for plant pigments to separate

1. Now, students will make observations of ink separation and use those observations to design an abstract art work. While steps 2-4 are structured in order to offer students the opportunity to see “what happens,” step 5 offers the chance for students to engage in open-ended exploration with materials, ultimately leading to the purposeful design of an original artwork.

2. Distribute a second strip of filter paper to students, and have them write their name or initials in pencil on the strip. In a second cup or jar, students should add about ½” of water.

3. Using a water soluble felt tip marker (like a Crayola marker), have students draw a line across one end of the strip and tape the other end to the middle of a pencil, so that it is just long enough to reach the water in the cup when the pencil is balanced across the rim. Adjust the filter paper or the water level so the end of the paper is slightly submerged.

4. The pigments in felt tip markers tend to separate much more quickly than the leaf pigments, providing a beautiful demonstration of pigment separation while the students wait for their leaf chromatograms.

INK CHROMATOGRAMS ctd.

Prompt observation as the marker pigment spreads:

-what colors do you see?

-what might determine how far each pigment spreads?

-what colors do you see when the inks separate?

-what pigments might you find in a green marker? A purple one?

5. Distribute a sheet of filter paper (or a full coffee filter) to each student, and have them write their initials in pencil on the edge. Based on what they know about chromatography and pigment separation, encourage students to experiment with the paper and markers to see what happens under a variety of circumstances. For instance, prompt students to experiment in one or more of these ways, or let them invent their own approach:

- Combinations or layering of different colors
- Different sizes and shapes of paper
- Different lengths or numbers of wicks
- Different applications of solvent
- Staggered applications of ink

6. Finally, ask students to use what they observed in the previous stage to intentionally design an art piece. Have them write down or express verbally what outcome they are hoping to see, then carry out their design on *a fresh piece of filter paper.*

Above: A variation in set-up to create radial separations. Filter paper resting horizontally across container with a wick of rolled filter paper submerged in solvent (in this case water, to separate washable marker pigments).

REFLECT AND DISCUSS *15 minutes*

If time allows, the plant leaf chromatograms can be left to develop for many hours, or overnight, and the pigment bands will continue to separate. Students can observe and discuss their plant chromatograms while they are still developing, and remove and dry the strips the next day.

1. Ask students to gather around their plant chromatograms (the filter paper with the separated pigments). Have students compare and discuss the results:

-how many different pigments do you see?

-are there similarities between each chromatogram?

-did the pigments separate in a particular order?

-did the pigments travel the same distance along the filter paper? If not, why do you think some pigments travelled farther than others?

-why do you think understanding plant pigments might be important to scientists? to artists?

2. Have students gather around their ink chromatograms and ask students to present their favorite piece. Ask:

-what techniques did you discover that created interesting visual results?

-could someone else use this technique to get similar results?

CLEANUP *5 minutes*

Have students empty and rinse cups, brushes and pipettes, and cleanup work area.

NOTEBOOKS *5 minutes*

Have students paste the dried chromatograms into their notebooks, and make note of their chromatography experiment: the procedures they used, their observations, results, and any further questions they would like to explore.

EXTENSION *30 minutes*

Chromatography can be used to separate individual components from many complex mixtures and is widely used in chemical analysis. In this 30-minute extension, students will test other plant material to see what pigments they contain.

Ask students to collect other plant materials with colors that interest them. These can be collected in the vicinity of the classroom (leaves, fruits, berries, flowers). With advanced notice, students can bring in items to test from home… around the house and in the refrigerator are good places to look for specimens.

Now that students are familiar with some of the common pigments in plants, have them follow the original procedure with the new plant material, and compare the results with their first chromatogram.

If unfamiliar pigments appear on the new chromatograms (such as red and purple pigments called anthocyanins) students can research their plant material to identify them.

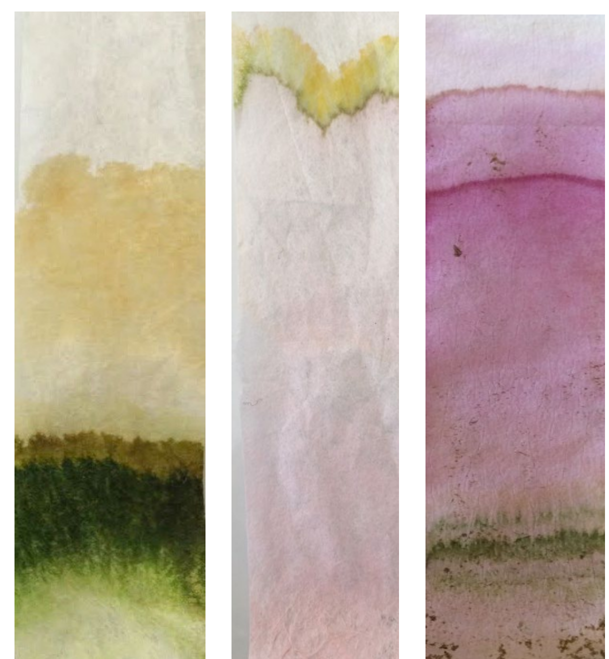
Above:
Begonia and Coleus plants are often available at nurseries and garden stores. Their decorative appeal comes from the distinct patterns of their leaf pigments, which have been developed into hundreds of colorful varietals.

Right:
Chromatograms showing the pigment separation of leaves from kale, begonia rex, and purple heart (tradescantia pallida). The begonia and purple heart leaves contain various red-hued anthocyanin pigments that are absent in the kale and spinach leaves. The anthocyanins also occur in many deciduous tree leaves that appear green until the chlorophylls break down in the fall, revealing the underlying red hues that give trees their autumnal color.

REFLECTION

When the new chromatograms have sufficiently developed into distinct bands, regroup and discuss the results.

> *Do you think any of the pigments are the same ones we observed in the spinach leaf chromatograms? Which ones?*
>
> *Are any of the pigments different? Which?*
>
> *What evidence do you have from your observations that support your conclusion?*
>
> *Color? Distance travelled? Other?*



COLORS OF NATURE / KIT 2

HOW DOES THE CHEMISTRY OF COLOR HELP US UNDERSTAND THE WORLD AROUND US?

INVESTIGATION 2 / HOW CAN WE MANIPULATE COLOR WITH CHEMISTRY?

PAINTING WITH CHEMISTRY

GRADES:

4-6

TIME REQUIREMENT:

60 minutes

SCIENCE STANDARDS (NGSS):

Performance Expectation:

5-PS1-4. Conduct an investigation to determine whether the mixing of two or more substances results in new substances.

Disciplinary Core Idea:

PS1.B: Chemical Reactions When two or more different substances are mixed, a new substance with different properties may be formed. (5-PS1-4)

ART STANDARDS (NCCAS):

VA:Cr1.1.5 Combine ideas to generate an innovative idea for art-making.

VA:Cr2.1.4 Explore and invent art-making techniques and approaches.

VA:Cr2.1.5 Experiment and develop skills in multiple art-making techniques and approaches through practice.

VA:Cr2.1.6 Demonstrate openness in trying new ideas, materials, methods, and approaches in making works of art and design.

OVERVIEW

Students explore a chemical reaction, and its effect on color, through the creation of a watercolor painting. Using red-cabbage juice as a painting medium, students explore adding acids and bases to change the color of the pigment in the red cabbage and expand their painting palette. A change in color is one of the indications that a chemical reaction has occurred when substances are mixed together.

LEARNING OBJECTIVES

- *Students will be able to discuss and give examples of how mixing two substances together can result in a new substance, or substances, through the process of chemical reaction.*

- *Students will explore and experiment with new art making techniques, and be able to apply their knowledge of chemical reactions to alter the colors of their painting materials.*

INSTRUCTIONAL APPROACH

This STEAM investigation is designed to introduce students to the relationship between **chemistry and color** by demonstrating a **chemical reaction** using red-cabbage dye mixed with acids and bases. Acids and bases react chemically with the pigments in red cabbage, resulting in a color change ranging from purple to blue-green to bright pink. The instructor should guide the students through questions and prompts that encourage:

- *observation of the materials and their interactions*
- *experimentation and modification of techniques based on observations*
- *analysis and discussion of results*
- *discussion of how artists and scientists use chemistry in their work*

The instructor should accept all student answers as value neutral.

ART BACKGROUND

Humans have long sourced **pigments** from the natural world to give color and meaning to their environment, from painting hunting scenes on the walls of caves with red-hued, iron-rich mud, to dying the robes of royalty a bright purple color with the mucus of hard-to-obtain Mediterranean sea snails, called *Murex*.

Humans have also manipulated, or taken advantage of, chemical reactions in the natural world to create pigments that are suited to specific purposes and desires. An early example of this manipulation is the intentional burning of sticks of wood to create black charcoal that could be used for drawing on a cave wall.

A more recent example is the development of **synthetic pigments** used to endow manufactured goods with an abundance of brilliant colors that occur only rarely in nature. Both of these examples are the result of humans taking advantage of chemical reactions that change the color of pigments.

For thousands of years, people have used their growing understanding of chemistry to create the vast array of colors we see around us in the world today.

Red iron ochre and white chalk pigments were used to paint the Cueva de los Manos in Argentina, possibly as long as 13,000 years ago. Most prehistoric art is dominated by colors such as red, black, white and yellow: color-fast pigments that occured abundantly as minerals or could be created by making charcoal.

Below, a modern dye-house in Morrocco prepares a palette of both synthetic and natural pigments to color a pile of fresh wool yarn.

SCIENCE BACKGROUND

When two or more substances interact with each other (such as wood and oxygen in a campfire) new substances can form (gases, water vapor, ash) as the result of a **chemical reaction**. Not all substances react chemically when mixed together, however. Many remain simply a mixture of two discrete substances. So how do we know whether or not a chemical reaction has occurred?

An **indicator** is a device that gives us specific information about the condition or state of something. A traffic light, for example, is an indicator that tells us whether it is our turn to stop, or our turn to go. An indicator can also give us information about the chemistry of a substance by giving us a detectable signal that a chemical change has occurred.

In fact, one of the **signs of a chemical reaction** between two or more substances is a **change in the color** of the resulting material. When we pull a partially burned stick of wood from our campfire, we find it has turned black. This new black substance, charcoal, is one of the products of a chemical reaction called pyrolysis, a breakdown of the organic molecules in the wood into smaller components caused by the intense heat of the fire. Another ubiquitous example is the distinct color of rust. When iron mixes with water it turns red, indicating a chemical reaction has occurred and the iron has been chemically changed to iron oxide, or rust.

In this investigation we will be using an acid-base chemical reaction to **change the pH** of a red cabbage dye solution and alter the color of its pigment compound, called **anthocyanin**.

pH is a numeric scale used to describe the **acidity** or **basicity** of an aqueous (water-based) solution, based on the concentration of hydrogen ions. Pure water is considered neutral, with a pH of 7. Solutions with a higher pH are considered basic (such as dish soap), solutions with a lower pH are acidic (such as lemon juice).

Anthocyanin is a common pigment found in plants and is responsible for the familiar colors of many flowers and fruits, ranging from blues to pinks to reds. In flowers and fruits the bright colors that anthocyanins create attract pollinators that help the plant reproduce. Anthocyanins can be found in leaves too, where they help protect plant cells from damaging wavelengths of light.

Anthocyanin pigments reflect different wavelengths of light depending on the specific structure of the pigment molecule. In an **acidic environment (low pH)** the anthocyanin molecule in red cabbage changes structure and reflects more red wavelengths, whereas in a **basic environment (high pH),** the anthocyanin molecule gains a proton and reflects more blue and green wavelengths (while absorbing the red and violet).

Anthocyanin, the pigment found in red cabbage, blueberries, and many other plants is the same pigment that colors Hydrangea blooms pink and blue. Because it reacts with acids or bases in the environment, gardeners can change the color of flowers a plant produces by adding amendments to change the pH of the soil.

COLORS OF NATURE / KIT 2 — How does the chemistry of color help us understand the world around us?

INVESTIGATION 2 / ACID BASE REACTIONS: RED CABBAGE PAINTING — How can we manipulate color with chemistry?

PREP

KIT MATERIALS

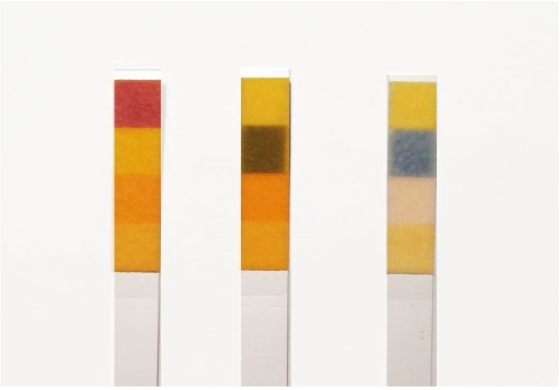
- **20g jar dehydrated red cabbage juice concentrate** (such as Red Cabbage Jiffy Juice)
- **64 oz white vinegar**
- **16 oz box baking soda**
- **Universal pH indicator strips, range 1-14** (3 per student)
- **3oz plastic cups** (3 per student)
- **pH indicator chart** (1 per groups of 2 students)
- **Watercolor paper.** 1 half sheet of 9x12" paper per student. Reserve 2 extra sheets for test strips. Any heavyweight student-grade watercolor paper will work, and is usually available in pads of 24 sheets.
- **3ml pipettes** (3 per student per student)
- **Watercolor brushes (**1 small, 1 large per student)
- **Permanent markers for labeling cups** (1 per working group)
- **Cooking oil** (1 cup)
- **Red and Blue food coloring** (4 each 0.3 oz bottles)

ADDITIONAL SUPPLIES

- **Water**
- **Paper towels/ wet wipes for cleanup** (1 roll)
- **Table covers or drop cloths to protect working area** (large garbage bags can be used)
- **Pencils** (1 per student)
- Scissors (1 pair for prep)
- **Additional MILD acids and bases for experiments:**

lemon juice concentrate, dish soap, and other liquids around the classroom can be used (students can identify and collect substances to test). NOTE: make sure that the students are not selecting highly basic or acidic products, such as strong cleaning agents, bleach, etc. as these can cause dangerous chemical reactions. All products used should be safe to touch without gloves.

RIGHT Classroom items that could be tested with the cabbage dye include foods, juices, soaps and other cleaners, plant fertilizer, hand cream, art supplies and so forth. Instructor should monitor students choices to avoid hazardous materials and take appropriate precautions.



Universal indicator strips (pH testing strips) and red cabbage both contain pigments that react to acids and bases. Color change is one of the clear indications a chemical reaction has occurred when mixing substances together.

SETUP *15 minutes. Set up in advance of the class period to maximize time for the investigation.*

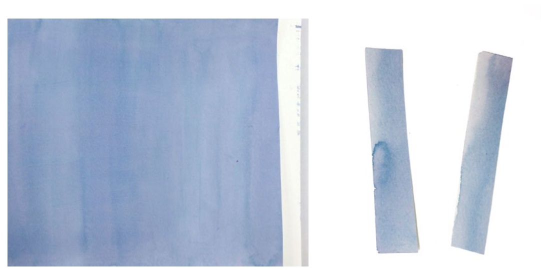
1. Protect working area. Use paper or plastic coverings on tables and dropcloths on the floor to minimize cleanup from cabbage-dye spills.

2. Prepare cabbage dye. For best results with painting, the cabbage juice concentrate should be mixed significantly stronger than the directions on the container. For each working group of 3 students, label a cup "red cabbage" with the permanent marker and mix 6 scoops of cabbage powder with 25mL water. A scoop and pre-marked beaker is included with commercially available red cabbage concentrate powder.

3. Prepare watercolor paper. Cut 9x12" watercolor paper into half sheets, one for each student's painting. Using a wide brush, coat one side thoroughly with the prepared cabbage juice and set these aside to dry. Drying time depends on classroom conditions and the sheets can still be used even if damp. Ideally, if time allows, students can coat their own watercolor paper with the red cabbage ink, writing their names on the reverse side of the paper and setting aside to dry. Coat a few extra full sheets for group experiments.

NOTE: Students benefit from having multiple exposures to new techniques and opportunities to change the variables of their experiments. If time and materials allow, students can be given additional paper, allowing them to create multiple paintings.

Use small cups to distribute cabbage dye, acids and bases to students. Be sure to label the contents of each cup! Coat the watercolor paper with the red cabbage dye, using a wide brush. When dry, the cabbage ink will appear purple and the paper can be cut for painting.



4. Prepare test strips. Using a wide paintbrush, coat a few full sheets of watercolor paper with the red cabbage solution and set these aside to dry. When dry, cut each sheet into approximately 1" wide strips, making enough for each student to have one. One sheet of paper makes twelve 1" x 9" strips, these can be cut in half if needed.

5. Create drying area. Adjacent to the working area, protect a large counter, table, or part of the floor with butcher paper or drop cloth. This area will need to be available for a several hours, depending on temperature and humidity, while the watercolors dry.

6. Prepare acids, bases and water cups. Pour a few tablespoons of white vinegar into small cups labeled "vinegar," making enough cups for groups of 2-3 students to share. Pour a tablespoon of baking soda into an equal number of cups and mix with enough water to dissolve it, and fill a third set of cups with plain water. Label all of the cups for identification.

INTRODUCTION: WHAT HAPPENS WHEN WE MIX DIFFERENT SUBSTANCES TOGETHER? *20 minutes*

1. Engage the students by having them engage in hands-on exploration of mixtures. Have students divide into pairs or small groups to explore mixing substances. Give each group one of the following mini-experiments to try:

   1. mixing oil and water
   2. mixing red and blue food coloring (a few drops each) in water
   3. mixing baking soda and vinegar

Ask students to make a prediction about what will happen when they combine the substances. Then have the groups mix a small amount of their substances in clear cups and carefully observe the results.

2. Ask each group to share their observations:

   -what substances did you mix?

   -what was the result of mixing these two substances?

   -do you think your mixture resulted in a chemical reaction?

   -what makes you think a chemical reaction did or did not occur? What is your evidence?

3. Ask students for examples of other substances they have tried mixing together (such as in the kitchen). What were the results? Prompt students to think about whether combining the substances resulted in a mixture or a new substance with different properties than the substances used to mix it:

   -have you ever mixed substances together that resulted in a new substance?

   -did a chemical reaction occur?

   -what was the evidence of a chemical reaction?

Suggest that when two substances are mixed together, they sometimes create a new substance. This process is called a chemical reaction.

4. Suggest that there are observable signs, or **indicators**, that let us know a chemical reaction has occurred when substances are mixed. Ask students what some of these indicators might be? Write student ideas and examples on the board and if necessary, prompt students with examples to help them come up with the following indicators of chemical reaction:

1. Color change
rusting iron turns reddish

2. Gas production
bubbles from baking soda/vinegar

3. Temperature change, or light emitted
handwarmers, glowsticks

4. Precipitate, formation of a solid material from mixing liquids
mineral scale in pipes or tea kettles and kidney stones are common examples of precipitates

NOTE: color change does not ALWAYS indicate a chemical reaction. Non-chemical color change is easy to predict: it will be a mix of the colors being added. Ask students what happened when they mixed the red and blue food coloring together (it made purple, or a mix of red and blue)?

5. Let students know that today, they will be experimenting with mixtures and chemical reactions in order to create their own artwork. Prompt students to think about where the colors around us come from. Draw attention to art supplies, clothing, printed matter, and other examples of pigments in the direct environment:

   -what do you think people used to draw or paint with thousands of years ago? to dye clothes with?

   -do you think certain colors were easier or harder to find? Which ones? Why?

6. Introduce the idea that thousands of years before humans understood chemistry the way we do today, they observed that certain substances would change color when mixed with other substances, or when exposed to heat or light. Without knowing exactly why this happened, they took advantage of these observations to manipulate and alter materials in their environment, allowing them to produce pigments and dyes that did not occur around them naturally, or in adequate supply.

Today we call that process of controlled chemical reaction **synthesis**, and use our knowledge of chemistry to synthesize all kinds of new substances that do not occur in nature, including many of the pigments we paint with.

INVESTIGATION PART I:
CHANGING CABBAGE COLOR WITH CHEMICAL REACTIONS *15 minutes*

1. Let students know that they are about to explore chemical reactions by mixing red cabbage pigments with other substances. Show students the prepared cabbage juice and (if the students did not prepare their own paper) let them know that this was brushed onto the paper in advance and allowed to dry.

2. Hand out a cabbage-coated test strip and a Cabbage Chemistry Chart (see p.10 for chart) to each student. Have the students tape their test trip vertically on the first column of the chart. They will use this chart to collect and record evidence that a chemical change has occurred as they test and observe various substances. Before they test and observe various substances, ask students:

-why might it be important to an artist or scientist to avoid cross-contaminating their materials with unclean tools?

Ask students to come up with a method to avoid contamination (using a dedicated brush or pipette for each substance, or cleaning tools thoroughly before using them with another substance).

Now, have students apply a drop of vinegar and a drop of dissolved baking soda to their test strips using the pipettes, labeling the strip and filling in their chart with the respective materials.

SAFETY NOTE: Remind students that mixing acids, bases, and other chemicals can be dangerous and they should NOT try mixing chemicals on their own without parental approval.

As students work, ask them to share their observations:

-what do you see happening? (cabbage pigments change colors)

-what does the color change tell you about the two substances you are mixing?

-what indicators of chemical reaction do you observe?

3. Encourage students to collect and test a few other classroom materials, and label the test strips accordingly. Limit materials to those that are safe to ingest or apply to the skin, such as foods, beverages, soap, and other personal care products. As students test various materials, prompt them to reflect on the color changes they observe.

As students test various materials, prompt them to reflect on the color changes they observe:

-what substances change the cabbage pigments different colors?

-what colors have you created?

-are there any substances that do not turn the cabbage pigment a new color?

-can you identify any similar characteristics between substances that turn the cabbage pink?... green?... other? no color change?

INVESTIGATION PART II:
PAINTING WITH CHEMISTRY *15 minutes +*

(If time allows, students can do multiple paintings)

1. This part is at the heart of the activity: allowing students to use the knowledge they just gained to purposefully create art. To start, hand out the half sheets of cabbage-coated watercolor paper that were prepared in advance (or by the students at the beginning of class).

2. Invite students to apply their discoveries --of the materials they tested and the resulting chemical color change when mixed with cabbage-- to create their own colorful painting on their cabbage-coated paper.

3. Establish an experimental zone using the extra full-sheets of cabbage-coated paper. Students can test ideas or materials on these shared sheets before applying them to their own paintings if they would like.

4. As students finish, have them set aside their paintings in the drying area. If time and materials allow, students who finish quickly can begin another painting.

INVESTIGATION PART III: ACIDS AND BASES *15 minutes*

1. Ask students as a group to list the substances that turned the cabbage strip similar colors. Collect responses on the board (Pinks: lemon juice, vinegar, ___; Green/blues: baking soda, soap, ___). Ask students: *what do these substances have in common?*

2. Introduce the terms **acid** and **base**. Many students have heard these terms and may be familiar with the concept. To connect to prior knowledge ask:

-what is another example of something acidic?
-something basic?

3. Let students know that the pigments found in red cabbage, called **anthocyanins**, are responsible for the blues, purples and pinks and red colors we see in many fruits, flowers, and leaves. Ask students: *what happens when we mix anthocyanins with various acids and bases?*

Anthocyanin is useful to scientists because it reacts with acids and bases and the color change can tell us whether a particular substance is an acid or a base. Most people don't want to carry around huge jars of cabbage juice to test for acids or bases though. *What other detectors or tools might we use to figure out whether something is acidic or basic?*

4. Introduce the pH test strips. Ask if anyone has seen or used them before, and what for? Let students know that pH is a scale used to measure the acidity or basicity of a water-based solution. The scale ranges from 0-14, with 7 being neutral. Lower than 7 is acidic, higher than seven is basic (also called alkaline). Pure water is neutral, with a pH of 7.
Prompt students to consider:

-why might scientists be interested in knowing the pH of something?

Some students are familiar with monitoring pH in their fish tank… prompt them to consider other bodies of water and how pH might be important to think about for animals living in the ocean, rivers, or lakes.

-why might artists be interested in knowing the pH of something?

Look around at art supplies in your classroom. Many of them will say "acid-free" including the cover of the watercolor paper pad. Why might an artist want acid free materials (hint: it has to do with changing colors)?

5. Have students, as a group, use the pH indicator strips to test all of the assembled substances they used for their paintings (each student can test a few). Students can set the wet strips on their paper plate to dry, and make a note of what substance each strip was used to test. Using the color chart included with the indicator strips for reference, have students make a note of what pH is indicated. Encourage students to record their observations in their Cabbage Chemistry Chart.

6. Ask students, as a group, to use the information collected with the pH strips to create a list of their painting materials, organized from lowest pH to highest (from most acidic to most basic), and the color produced when mixed with the cabbage pigment. Write the results on the board. Students can write these in their notebooks and include their test strips alongside their chart when dry.

REFLECT: WHAT DOES CHEMISTRY HAVE TO DO WITH COLOR? *10 minutes*

Ask students to bring their test strips and gather around their paintings in the drying area to observe and discuss the results. Prompt students to think, pair, share:

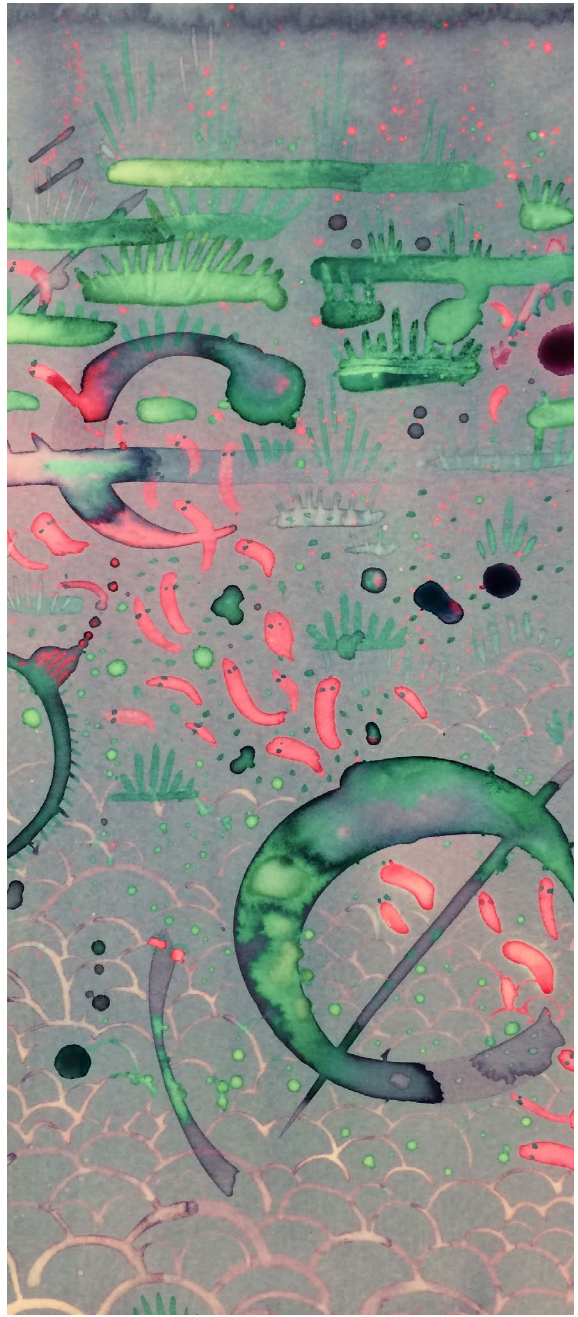
-what did you learn about your painting materials from the pH test strips?

-how might you use this information to create cabbage chemistry paintings in the future?

-what effects and colors were you able to make by combining acids and bases with the cabbage dye?

-in what ways do you think understanding the chemistry of color is important to the work of artists? Or, why would artists need to understand the chemistry of color?

-in what ways do you think understanding the chemistry of color is important to the work of scientists? Why would scientists need to understand the chemistry of color?



CLEANUP

Have students empty and rinse cups, wash brushes and cleanup work area.

Above: A paper towel used to clean up the activity turned a wide range of colors, some of which didn't appear in our other tests. What does that tell us about the chemistry of the paper towel? Left: painting on cabbage coated paper with acids and bases.

NOTEBOOKS

When dry, students can paste their cabbage dye test strips and pH test strips into their notebooks, and make note of which substance they tested with each strip, and whether the resulting color indicated an acid, a base or a neutral substance. Have students reflect on their cabbage-ink painting experience: the procedures they used, their observations, the results of their experiments, and further questions they would like to explore. If desired, corresponding paintings can be added to the notebooks when dry.

CABBAGE CHEMISTRY OBSERVATION CHART

Use the following chart to organize your data as you test mixing various substances with the cabbage pigments:

Tape cabbage strip below	What was the substance that you added to the cabbage strip?	Observe: what color did the cabbage strip turn?	pH of the substance

Make a list of the substances that turned the cabbage strip a similar color. What do you notice about their pH values?

GRADES:

4-6

TIME REQUIREMENT:

60 minutes

SCIENCE STANDARDS (NGSS):

Performance Expectation:

5-PS1-4. Conduct an investigation to determine whether the mixing of two or more substances results in new substances.

Disciplinary Core Idea:

PS1.B: Chemical Reactions When two or more different substances are mixed, a new substance with different properties may be formed. (5-PS1-4)

ART STANDARDS (NCCAS):

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VA:Cr1.1.5 Combine ideas to generate an innovative idea for art-making.

VA:Cr2.1.4 Explore and invent art-making techniques and approaches.

VA:Cr2.1.5 Experiment and develop skills in multiple art-making techniques and approaches through practice.

VA:Cr2.1.6 Demonstrate openness in trying new ideas, materials, methods, and approaches in making works of art and design.

COLORS OF NATURE / KIT 2

HOW DOES THE CHEMISTRY OF COLOR HELP US UNDERSTAND THE WORLD AROUND US?

INVESTIGATION 3 / HOW CAN LIGHT AFFECT THE CHEMISTRY OF COLOR?

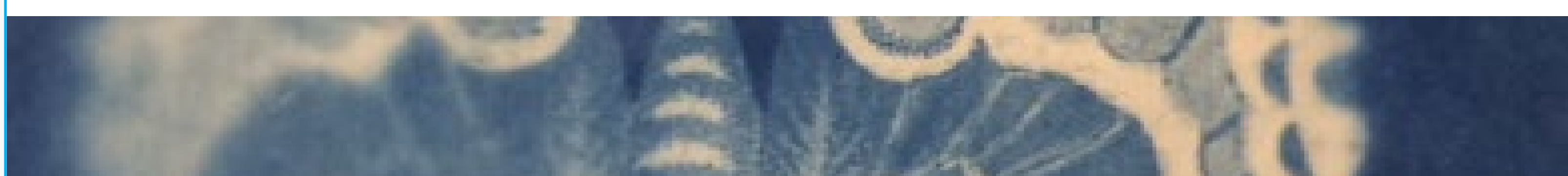
CYANOTYPES

OVERVIEW

In this investigation, students will explore a chemical reaction that is mediated by light through the creation of a cyanotype print. A cyanotype is made when chemicals on specially prepared paper react with light, making a new chemical substance. The reaction can be detected through a color change. Areas on the paper blocked from light exposure do not undergo a reaction, leaving an image behind on the paper. Thus, a beautiful art print can be created through chemistry.

LEARNING OBJECTIVES

- *Students will be able to demonstrate and explain how new substances are formed during a cyanotype chemical reaction, as indicated by a color change.*
- *Students will experiment with different materials to create a variety of artistic outcomes with cyanotypes.*



INSTRUCTIONAL APPROACH

This investigation is designed to introduce students to a chemical reaction driven by light. The cyanotype paper is coated with special chemicals that react with UV to create a permanent pigment. Students selectively block the paper from exposure to sunlight in order to create an image.

The process is a quick and stunning demonstration of the relationship between chemical reactions and color. The investigation provides a good foundation for students to reflect on their own observations of color changes resulting from exposure to light (fabric fading, skin tanning, etc).

It is also an opportunity to draw students' attention to the broader implications of such observations. Experiments with the chemistry of color led to the development of photography, which in turn fundamentally changed the way we communicate information through imagery.

The instructor should guide the students through questions and prompts that encourage:

- *observation of the materials and their interactions*
- *synthesis of observations with prior knowledge*
- *analysis and discussion of results*
- *discussion of how artists and scientists use chemistry in their work*

Accept all student answers as value neutral.

SCIENCE BACKGROUND

Photochemical reactions are **chemical reactions** initiated by the absorption of energy in the form of light. Photochemical reactions are not only responsible for many colorful phenomena in nature; they are also essential to life on earth. Plants rely on a photochemical reaction, called **photosynthesis,** which uses sunlight to convert water and carbon dioxide into storable energy. The products of this reaction are glucose and oxygen, which in turn sustain animal life.

A photochemical reaction is also what makes it possible for us to see the world around us. Specialized cells in our eyes contain a pigment called rhodopsin that converts light into electrical signals, giving our brain information on what we "see".

Our sun emits radiation in a broader range of the electromagnetic spectrum than we can detect with our eyes. We see only the wavelengths from from red (through orange, yellow, blue, green) to violet. Just beyond visible violet there is a higher energy wavelength called ultraviolet, sometimes shortened to UV. These are the waves that are responsible for causing sunburns, as well as many other photochemical reactions.

The **cyanotype** process is an early photographic technique introduced in 1842 by the British scientist John Hershel after he discovered a photochemical reaction of soluble iron salts. Exposure to ultraviolet (UV) radiation in sunlight alters the chemical structure of these salts to create the insoluble pigment known as Prussian blue. An mixture of two soluble iron salts is used to coat a sheet of paper, which in turn is exposed to sunlight to "fix" the color.

Any UV-blocking object, such as a leaf, can be used to selectively mask exposure of the paper and prevent the photochemical reaction. After washing the paper, the soluble salts that have not been exposed to UV rinse away, leaving a silhouette of the leaf against a field of Prussian blue.

Right: cyanotype paper in the sunlight with found leaves and seed pods to block exposure to UV light in select areas.

ART BACKGROUND

Humanity's insatiable desire for brilliant colors, with which we adorn ourselves and our surroundings, has driven advancements in chemistry throughout history.

Over 3000 years ago, the Phoenician people of the eastern Mediterranean took advantage of a photochemical reaction to create the first colorfast (non-fading) purple dye. They discovered that a colorless secretion from the *Murex* sea snail began to turn red when exposed to sunlight, and from this secretion they developed a reddish-purple textile dye that became more brilliantly colored over time with exposure to light. The effect of this rare dye was so prized that its use was restricted to ceremonial garb for the imperial court. The association between purple robes and royalty sticks with us to this day.

Left: a Byzantine robe dyed with Tyrian purple, a dye obtained from the Murex sea snail.

Continuous experimentation with the chemistry of color led to the development of photography in the 1800s. The British botanist Anna Atkins popularized cyanotype prints, an early photographic method, shortly after her friend John Herschel discovered the photochemical reaction of certain iron salts.

While Herschel used these "blueprints" to reproduce notes and diagrams, Atkins placed botanical specimens directly on paper coated with the photosensitive cyanotype emulsion and exposed them to sunlight. She used this process to document British algae for a book on the subject, which she published in 1843.

Photographs of British Algae: Cyanotype Impressions is considered the first book to use photographic images for illustration, and Atkins is recognized for her creative use of the cyanotyope process as the first female photographer.

Above: An illustration from *Photographs of British Algae: Cyanotype Impressions* by Anna Atkins.

KIT MATERIALS

- **Cyanotype "sunprint" paper** (at least 3 sheets per student)
- **Clear plastic side-loading sheet protectors** (one per student)
- **Black permanent markers** (combination of fine, medium and bold tip, enough total for each student to have one marker, although tip sizes can be shared)
- **Sunscreens** (3 bottles with varied SPF, low and high)
- **Construction paper** (1 pack, approximately 100 sheets, for cut-out shapes)
- **Clear acetate** (1 sheet per student)
- **Anna Atkins** example prints
See online resources:
http://www.colorsofnature.org/education-kits

Materials can easily be collected around or outside the classroom. Leaves, seedpods, insects, and other interesting shapes can be used to create a print, such as this selection of equisetum arranged by the pioneer of cyanotypes, Anna Atkins.

ADDITIONAL SUPPLIES

- **Small objects with interesting shapes** collected in vicinity of classroom (such as leaves, twigs, flowers, rocks, feathers, cut paper, school supplies, etc.)
- **Water source** (Sink or a large tub filled with water for rinsing prints)
- **Dark cloth or black plastic sheeting** (such as garbage bags, to block out light from classroom windows if needed)
- **Kitchen timer or clock** (1)
- **Scissors** (1 per student)
- **Drop-cloths or butcher paper for drying cyanotypes** (3, or total area about 1 square foot per student)

SETUP *10 minutes*

1. Assemble materials.

2. Darken work room. Cyanotype paper is exposed by UV light. Every effort to minimize sunlight (close shades, or cover windows) in the working area will help reduce accidental exposure. Indoor lighting is designed to minimize UV radiation, so keeping a few lights on to illuminate the space should not negatively affect the process.

3. Create rinsing station. After exposing the prints in sunlight, students will need to wash their paper to "fix" the print and stop further exposure. This is best performed in a sink with running water, but if a sink is not available or more rinsing areas are needed, a large tub of water or even an outdoor hose can be used to halt exposure. Ideally, the rinsing station should be separate from the working area in order to keep unexposed cyanotypes dry. If the cyanotype paper gets wet prior to exposure, it will not develop.

4. Create drying station. Protect an area with drop-cloths where students can leave their wet cyanotype prints to dry. Drying time will depend on the temperature and humidity, but plan on using an area that will not conflict with subsequent activities.

INTRODUCTION *10 minutes*

1. Engage students by prompting them to think about everyday examples of how light exposure can change the way something looks. Ask:

-have you ever observed something change color when left in the sun? (fading fabric, yellowing paper, transition lenses in glasses that darken in the sun, skin tanning)

Write down ideas on the board, accepting all answers as value neutral. Explain that not all of these changes involve a chemical reaction, but that light can cause chemical reactions to take place.

2. Recap the ideas learned in *Investigation 2:* there are many different kinds of chemical reactions, and one that we explored was how cabbage pigments change color when we change pH. The red cabbage dye changed color (to pink, blue, or green) depending on the pH, indicating a chemical reaction had occurred.

Then, let students know that today we will be investigating another colorful reaction called a **photochemical reaction**, and using it to create art. “Photo” comes from the Greek word for “light,” so photography means “light writing.” As the name suggests, this kind of chemical reaction happens with the help of light.

CYANOTYPE PROCESS EXPLORATION *15 minutes*

1. Show students a sheet of the unexposed cyanotype paper (but keep the rest of the sheets in the black plastic protective sleeve until they are ready to be used). Some students may be familiar with “sunprints” and can be encouraged to share their prior experience.

2. Let students know that one side of the paper has a special coating that contains two different chemical compounds. Both of these compounds are highly soluble in water, meaning they can easily be dissolved in water and washed off the paper. Ask for a volunteer to test this assertion by rinsing the unexposed sheet. The blue pigment will wash away.

3. Ask for a volunteer to keep track of time. The exposure time varies greatly depending on sunlight conditions and you can test this as a group. In bright sunlight, the photoreaction can happen in ten seconds. On a cloudy day, it can take five minutes or more to expose the paper.

Take a new unexposed sheet of cyanotype paper. Hold the sheet of paper tightly between your two hands with fingers spread so that one hand blocks exposure to light on the blue side. Ask the students to follow you outside. When you reach natural light, keep your hands pressed together on the paper with the blue side up and have the volunteer begin timing. Have the students watch the paper carefully. In bright light, the paper will begin to fade to a pale blue almost immediately. In overcast conditions it can be harder to detect the changing color of the paper. If you are not sure, lift one of your fingers off the blue side to compare the color of the exposed area to the unexposed area. If the silhouette of your finger is visible as a distinctly darker blue shape, your paper is ready. Ask your volunteer to record the exposure time and head inside, keeping your hands in place until you are back in the darkened workroom, away from sunlight.

4. Remove your hands and show the students the light blue paper with the dark blue shape where your hand blocked the sunlight. Ask:

> *-what changes did you observe where the paper was exposed to sunlight?*
>
> *-why don't you think we saw these changes occur under the indoor lights?*
>
> *-what might there be in sunlight that isn't in the classroom lights? (what do we try to block when we spend lots of time in the sun? UV light!)*

It should be apparent that the paper has visibly faded where exposed, and remained the same where your hand blocked the light. Ask students to predict, based on their earlier observation of rinsing the soluble blue pigment off the unexposed paper:

> *What will happen to the exposed and unexposed areas when we rinse the paper?*

5. Proceed to rinse the paper until the water runs clear. As before, the unexposed pigments will wash away, leaving blank white paper where your hand blocked the light. At the same time, the pale blue areas that were exposed to the sunlight will begin to darken to a deep blue. They will continue to darken as the paper dries. Ask students to think-pair-share:

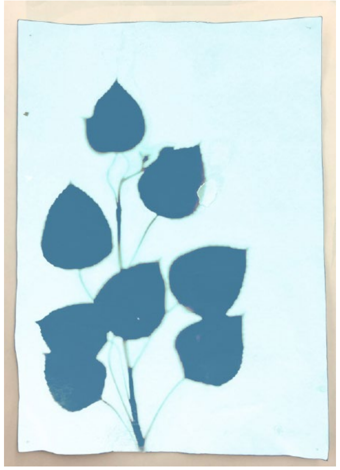
-what happened to the pigments that were exposed to the sunlight?

-have you observed anything similar to this elsewhere?

-what happens to your skin when you are out in the sun for a long time without sunscreen? (sun tans are also the result of a photochemical reaction with UV)

6. After students have had a chance to discuss with each other, let them report out. Share that the **cyanotype** process relies on a **photochemical reaction**. Ultraviolet rays in sunlight are absorbed as energy by one of the compounds (ammonium iron citrate) in the coating, changing it to a form that combines with the other compound in the coating (ferricyanide).

The products of this chemical reaction are two new compounds: soluble iron salts and an **insoluble pigment called Prussian blue**. Insoluble means it cannot be washed away. The soluble iron salts are a light yellow color, which is why the paper appears very pale after exposing it to sunlight. When the paper is rinsed, these soluble iron salts wash away, revealing the insoluble Prussian blue. Any area of the coating that has not been exposed to UV light will remain soluble, leaving the paper white.



Before rinsing, the cyanotype paper will appear a faded dull yellow where it was exposed to the sunlight. This color change is an indicator of the chemical reaction between the cyanotype pigments and the UV rays. The yellowish color is due to the soluble iron salts, and washes away during rinsing, leaving the insoluble prussian blue pigment on the paper.

The areas that were blocked from exposure will still be the light blue color of the (soluble) cyanotype emulsion, which, because it has not been fixed by the sun, washes away when rinsed.

CYANOTYPE EXPERIMENT and DESIGN *15 minutes*

1. Let students know that cyanotypes were one of the earliest photographic methods, and introduce them to work of Anna Atkins, a scientist and artist who used the cyanotype process to illustrate her books on botany.

2. Invite students to investigate and experiment with the cyanotype process to create their own prints.

3. Distribute one piece of cyanotype paper to each student and have them write their names in pencil on the white side.

4. Show the students the other materials available to them: acetate, construction paper, scissors, and permanent markers. They can cut out shapes from construction paper to experiment with blocking areas of the paper from UV rays. The clear acetate sheets can be drawn on with permanent markers and overlaid on the paper (the acetate will not block rays, but the marks made on the acetate will). They can also collect things with interesting shapes to use such as leaves, shells, or other objects of their choosing.

The clear sheet protectors can be used to sandwich loose objects onto the cyanotype paper, keeping the arrangement from shifting during exposure. If supply is limited they can be cut down, or wiped with rubbing alcohol to remove the marks.

CYANOTYPE EXPERIMENT and DESIGN *ctd.*

5. Remind students of the exposure time of the demo print. If there is a wall clock or a timer that can be stationed in view of the exposure zone students can keep an eye on it to help them judge exposure time.

6. As students return from exposing their first print, direct them to the rinsing station, and then instruct them to leave the wet print in the designated drying area. Remind them to dry their hands before distributing a second sheet of paper: wet fingerprints on unexposed paper can cause spots on the finished print. Which of course is fine, if that is their intention!

7. Encourage students to analyze the outcome of each print, making notes of satisfying effects and troubleshooting disappointing ones before embarking on the next print. More exposure? Less exposure? A different method for blocking UV?

8. 15 minutes before the period ends, let students know they should be rinsing their final cyanotype.

REFLECT *10 minutes*

Ask students to set their cyanotypes in the drying area and gather around to observe and discuss the results. Ask students to think, pair share, around the following prompts:

-what effects were you able to achieve by blocking UV with different materials?

-what else do you think you could do with the cyanotype process?

-in what other ways do you think photochemical reactions are important to the work of artists?

-in what other ways do you think photochemical reactions are important to the work of scientists?

NOTEBOOKS

When dry, students can paste the cyanotypes into their notebooks, making note of what they used create each one. Have students record the process and reflect on the experience.

-how might you expand upon this technique?

-what other applications might the cyanotype paper be useful for?

-what other tools or materials could you use to adjust the outcome of the resulting print?

CLEANUP

Have students collect reusable materials, dispose of materials that cannot be reused, and cleanup water spills.

EXTENSION *30 minutes*

Now that the students are familiar with the photochemical reaction between UV light and cyanotype pigments, they can use the process to investigate the effectiveness of products marketed to block UV, such as sunscreens and sunglasses.

Gather a variety of sunscreens with different SPF ratings and sunglasses if available. The sunscreen can be applied to the outside of the clear sheet protector (with the cyanotype paper sandwiched inside) using a paintbrush, fingers, or sprayed on. Students can then expose their cyanotype paper, as above, to compare the UV blocking capabilities of various sunscreens, sunglass lenses, or even test whether any of the lights in the classroom are emitting UV. Prompt students to brainstorm other possible techniques for blocking or exposing the cyanotype paper, and other possible uses for it.