The Tech Interactive

Biotinkering Programs for Science Centers

Draw with DNA

SEPA SCIENCE EDUCATION PARTNERSHIP AWARD
SUPPORTED BY THE NATIONAL INSTITUTES OF HEALTH

Stanford MEDICINE | Department of Genetics

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Draw with DNA Overview

Science Center Experience

Like all living things, fruit contains DNA in its cells. DNA is the instruction manual for life. In this activity, visitors take a close look at real DNA that they extract from a fruit of their choice and then make something with it. They mix and dissolve it with different watercolor inks to make a custom DNA-infused marker. Finally, visitors get to test out their marker and draw unique pieces of art, each of which secretly contains the complete instruction manual for a piece of fruit.

Subject
Genetics

Ages
8+

Duration
15-20 min

Key Concepts
DNA, precipitation, solubility

Activity Goals

- Enable visitors to build a colorful marker with custom-made ink infused with a DNA message.
- Provide opportunities for hands-on engagement with real lab tools and phenomena that support visitor-driven product design and creation.
- Normalize experimental failures by providing ways for visitors to support each other and emphasize the authentic power of science as a collaborative endeavor.

Operational Considerations

Base Biology	Format Complexity	Lab Requirements	Cycle Length	Cost
Fruit DNA	Medium: Biological Product	Freezer	Single session	$$$

Cycle Details

A full *Draw with DNA* cycle can be completed in a single 15-20 minute visitor experience as all steps of the activity happen in real time.

Background Information

DNA as Long-term Data Storage

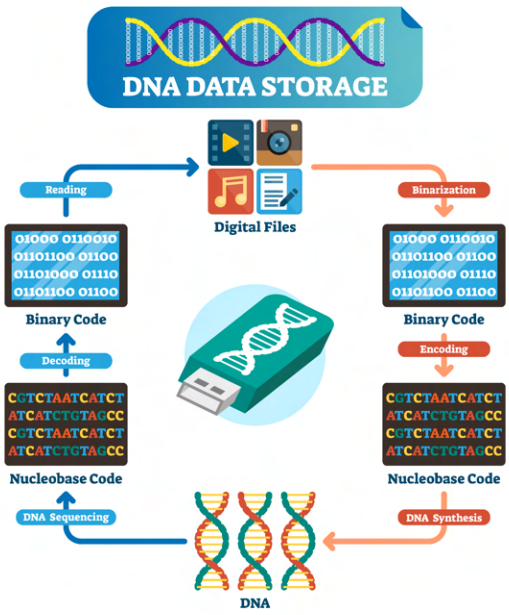
First proposed in the 1950s, the idea of using DNA as a way to store digital information has recently been turning into a reality. Humans generate an increasingly vast amount of digital data each year, but it is often difficult to retrieve older data as storage methods quickly become obsolete. In contrast, DNA is unlikely to go out of style. DNA has been the primary format for encoding hereditary information for billions of years on this planet.

DNA is also a very compact molecule that can contain a staggering amount of information in a small amount of space. For example, a DNA archive the size of a poppy seed could fit 6000 copies of all the data from the Library of Congress.

Under proper conditions, DNA can last for an extraordinarily long time. For example, scientists have successfully retrieved genetic information from a mammoth that was over one million years old.

While this is still an emerging field with technical limitations, it is already being incorporated into some archives. For example, the French National Archive now contains two historical documents in DNA form: The 1789 Declaration of the Rights of Man and of the Citizen and the 1791 Declaration of the Rights of Women and of the Citizen. These two texts are stored in the archive in the form of small, DNA-filled capsules and kept alongside other precious documents.

Other scientists have stored image files in DNA form and even come up with a method to retrieve an individual image from a set of 20.



Downsides of DNA Data Storage

While the cost to create custom DNA pieces continues to decrease, synthesizing long pieces of DNA remains expensive. Currently, it costs around $0.05-$0.10 per DNA letter. It is also not an instant process, and turnaround time for commercial DNA synthesis is on the order of days to weeks.

Retrieving the information from DNA requires special machines and equipment and like synthesizing DNA it is still relatively expensive. Today, you can sequence an entire human genome (6 billion DNA letters) for less than $1000. And even at the world record sequencing pace of 5 hours, it is rather slow compared to other data formats.

DNA is sensitive to temperature changes and should be kept in a cool, dry place for optimal storage. Under proper conditions, DNA can last for hundreds of thousands of years.

Amount of Data in the DNA Marker

While watercolor markers are not the ideal conditions to store DNA for the long term, each marker will contain a vast amount of information when created: each will have thousands of copies of a fruit's entire genome. A single copy of a banana's genome contains around 600,000,000 letters of DNA code. As DNA is a two-bit code, this translates to about 150 megabytes of data per banana genome. Now imagine thousands of copies in a single marker, and you're looking at around a terabyte of data!

Useful Vocabulary

Term	Definition
Cell	The smallest functional unit of life. Complex organisms (including fruits!) are made of many cells.
DNA	The molecule that contains the genetic instruction manual for a living organism. DNA is found inside cells.
Extract	(verb) The act of removing or taking something out. In molecular biology, scientists describe the process of taking DNA out of a sample as a *DNA extraction*.
Precipitate	(verb) In chemistry and molecular biology, this is when a substance appears in solid form from within a solution. (noun) The solid substance that appears in such a reaction.

Visitor Experience

Operational Summary

Context

Draw with DNA leverages lab processes and protocols that can be conducted in real time, allowing for the experience to be completed in 15-20 minutes. It does not depend on visitor-produced material supply chains, so it can be operated in any space and is easy to pop up at any frequency or cadence.

This activity was created as a facilitated experience that supports visitors through four hands-on steps: fruit selection, DNA extraction, marker creation, and drawing. The activity facilitator guides visitors through the protocol steps, offering assistance as needed and highlighting the locations where visitors have individual choice and opportunities to customize their products.

Activity Outline

1. Introduction and Fruit Selection
    - Facilitator gives an overview of the activity.
    - Visitors select a fruit to use in their marker.
2. DNA Extraction Station
    - Facilitator briefly introduces DNA.
    - Visitors extract DNA from fruit.
3. Marker Creation Station
    - Visitors dissolve DNA in watercolor ink.
    - Visitors assemble markers.
4. Drawing Station
    - Visitors test out their DNA markers and create unique art.

Introduction and Fruit Selection

Overview

Provide a brief overview of the activity to orient visitors to the nature of the experience. Designate a location for visitors to choose the fruit they will use for the activity. Frozen fruit can be pre-assembled in labeled baggies to make distribution, selection, and squishing easier. Consider using compostable baggies to reduce plastic waste from the activity.

Essential Materials	Individual ● Frozen fruit ● Baggies *Optional:* Bag labels to identify fruits if pre-assembled
Example Setup	

Engagement Strategies

Cultivate Confidence and Agency

- Providing opportunities to choose materials at the beginning of the procedure helps to establish visitor agency from the start.

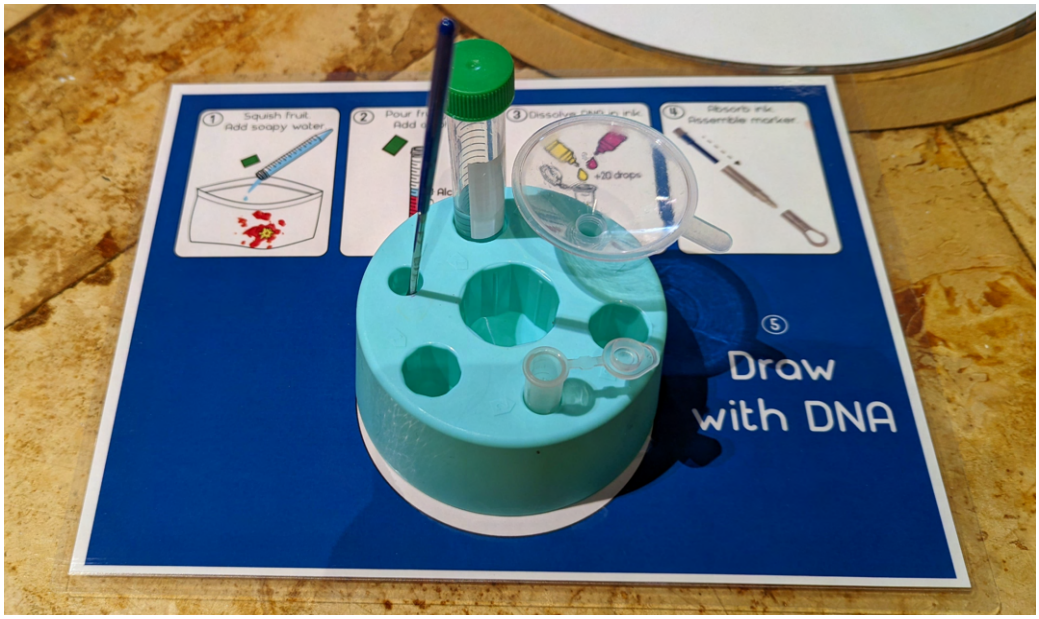
Make Community-Relevant Connections

- Consider including fruits that are culturally relevant to your audiences, even if they aren't the best performers (like mango!).

DNA Extraction Station

Overview

Visitors proceed through a standard DNA extraction and precipitation protocol to isolate DNA from their chosen fruit. Content extensions can be introduced throughout the procedure, including why soap breaks open cells or how precipitate is the opposite of “dissolve.” To ease flow through the process, offer individual work stations for each visitor and provide tubs of soapy water for visitors to put their used equipment into. Once visitors have isolated and observed the DNA in their tubes, they can move to the Marker Creation Station.

Essential Materials	<u>Individual</u> ● Tube rack ● Test tube with 6-8 mL lysis buffer ● Scoop ● Funnel <u>Shared</u> ● 95% alcohol ● Trash bins ● Tubs of soapy water for reusable supplies
Example Setup	

Key Visitor Steps	1. Squish the fruit.
	2. Lyse the fruit cells.
	  a. Pour lysis buffer into the baggie and gently mix.
	  b. Transfer fruit/soap mixture into a test tube with aid of a funnel.
	3. Precipitate the DNA from the fruit.
	  a. Add alcohol to make a ~1 cm layer on top of the fruit/soap mixture.
	  b. Observe the DNA.

Engagement Strategies

Highlight Authentic Science Practices: Normalize Failure

- Some experiments fail, often for no explicable reason other than “bad fruit.” Take a moment to address that not all biology experiments work, even for experienced scientists. Point out that scientists work in teams and can borrow supplies from a lab partner (or another visitor).

Foster Scientific Curiosity

- After precipitation has started, encourage visitors to spend time observing their DNA. The phenomenon of making something invisible visible is exciting and inspiring to many visitors.

Cultivate Confidence and Agency

- Visitors respond very positively to seeing authentic science tools (e.g., 15 ml Falcon tubes, Eppendorf tubes, lab spatulas, and tube racks). To help to facilitate quick and successful engagement with these unfamiliar and potentially intimidating scientific materials, however, provide pre-set stations with all the required materials organized in a rack.

Marker Creation Station

Overview

Visitors make custom-colored markers that contain the DNA isolated from their fruit. This provides additional context for a potential use of the DNA that visitors have extracted. This can help visitors conceptualize the broader role of DNA as information; in this case, their fruit DNA becomes a “secret message” hidden in the art they make with their marker. Provide visitors with all relevant components from the marker kit. Prior assembly of some parts of the marker (e.g., body, tip, and cap) will streamline the distribution. Once visitors have completed their markers, they can move to the Drawing Station.

Essential Materials	<u>Individual</u> ● Marker pieces (may vary depending on kit or source used) ● Ink-mixing containers (e.g., 2 ml Eppendorf tubes) <u>Shared</u> ● Ink bottles
Example Setup	 

Key Visitor Steps	1. Transfer DNA to a fresh microcentrifuge tube. 2. Choose colors of ink and add drops. 3. Wait for the DNA to dissolve in the ink. 4. Place the cotton marker core into the DNA/ink mixture and allow it to absorb. 5. Assemble the marker.

Engagement Strategies

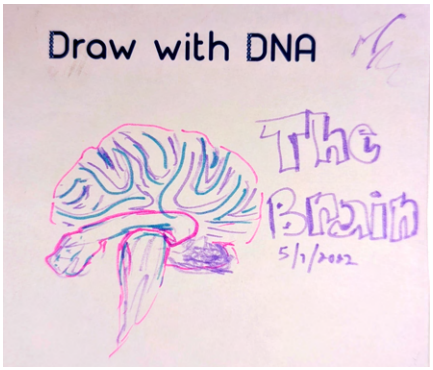
Support Creativity

- Visitors often forget all artistic knowledge when working in a science lab. It can be helpful to tie in artistic practices (e.g., the color wheel) to help visitors more successfully design and create desired marker colors.
- Showcase visitor choice in the process by offering multiple colors of ink bottles for visitors to share for custom color blending for the marker.

Drawing Station

Overview

Visitors can test out their brand new DNA markers and create whatever they are inspired to. This station should be set up with blank sheets of paper and any other drawing accessories desired.

Essential Materials	<u>Shared</u> • Paper
Example Setup	 

Engagement Strategies

Support Creativity

- Consider creating a location where visitors can leave behind their artwork to share with the community and serve as inspiration for future visitors.
- Instead of individual small papers, consider a single large sheet for collaborative artwork.
- Encourage visitors to share DNA markers with each other to access color variety.

Common Visitor Questions

Visitors often ask unpredictable or incredibly specific questions about the content or process of an activity while they are participating in the experience. Every audience will have different interests or prior knowledge that they bring to the experience. Below are examples of the most common questions we hear from visitors and the types of answers we aim to provide.

Question	Information
Is this pure DNA?	*Not entirely, but most of it is DNA.* Some other "stuff" will come along with the DNA. Berries have a lot of a protein called pectin, which also precipitates in alcohol. That's some of what you see in the DNA mix. The pectin will also dissolve in water, so it will mix into your ink.
Why didn't my fruit produce DNA?	*You might have just gotten a bad piece of fruit.* DNA is a little bit fragile. If your piece of fruit wasn't very good for some reason, or if it thawed and then refroze, it might not have had as much good-quality DNA. Luckily scientists work in teams. You might be able to borrow some DNA from a lab partner for the next step.
Does the DNA really go into the marker?	*Yes!* DNA dissolves in water-based liquids, like ink. It will be mixed in and then absorbed throughout the marker. That means everything you draw with the marker will have some of the DNA mixed in!
Why doesn't my DNA look like the classic picture?	*It's too small to see without a microscope.* You would need a very strong and fancy microscope to see the actual double helix shape, but it is there. The DNA in your tube is visible to the naked eye because it's all clumped together. It's a lot like a shirt, which is made up of lots of tiny threads that are too small to see unless they are clumped together.
How long is DNA?	*Very. If all the DNA in one cell were stretched out, it would be ~6 ft (2 m) long.* The total DNA in your body (around 37 trillion cells!) would stretch over 22 billion miles. That's more than 100 round trips to the sun! This is a bit of an estimate since we don't know exactly how many cells are in a human body, but it gives you a general idea of just how long DNA really is.
What does the salt do?	*It helps break open the fruit cells so that they release their DNA.* Positively-charged sodium neutralizes the negative charge of the phosphate backbone. This makes it harder for the DNA to find and associate with positively-charged water molecules.

Why does DNA dissolve in water?	*DNA and water have opposite charges (positive and negative), which means they can mix together really well.* DNA has a negative charge from the phosphate molecules that make up the backbone of the DNA helix. The negative charges interact with the positive charge on each hydrogen atom in water. These attracting charges help the DNA mix and associate with the water (aka dissolve).
Why does adding alcohol cause DNA to precipitate?	*DNA can't dissolve in alcohol, so it clumps up.* Unlike water, alcohol doesn't contain many charged molecules. For that reason, the negatively charged DNA isn't attracted to alcohol molecules. With enough alcohol molecules, the water is outnumbered and the DNA can't stay dissolved.

Backend Preparations

Overview of Components

The biological base of *Draw with DNA* is DNA extracted from fruit, which is a non-living biological material, so minimal ongoing support is needed to operate this activity. When running this activity at scale, however, it can be helpful to do many of the preparation steps in advance and in bulk. This includes preparing baggies of fruit, setting up ready-to-use aliquots of lysis buffer, refilling alcohol bottles, and cutting drawing paper.

Backend preparations for this activity include:

1. Selecting and Preparing Fruit
2. Preparing DNA Extraction Reagents

Selecting and Preparing Fruit

The most time-consuming and sensitive backend step is preparing the fruit. Fruit can either be prepared before each activity session or in bulk and frozen for future use. The quality of DNA is degraded by repeated freeze-thaw cycles, so care should be taken to prevent or minimize unnecessary thawing of the fruit.

Materials

Reusable Equipment	
Item	**Notes**
Freezer	Lab-grade is ideal as consumer-grade freezers usually have regular defrost cycles so fruit does not last very long
Knife	
Cutting Board	

Consumable Supplies	
Item	**Notes**
Fruits	Provide several options - berries, bananas, tomatoes, and kiwis all work well
Baggies	Snack size works well
Labels	Optional but recommended if baggies with fruit are opaque

Procedures

1. Select ingredients for the visitor-facing activity.
    - Choose several different fruits to give visitors the ability to select their starting material.

        - Fresh fruit generally yields the most success for DNA extraction and can be chosen at peak ripeness for easier squishing.
            - Berries, bananas, kiwis, tomatoes, and mangos all work well. Cherries also work but typically have a lower DNA yield.
        - Frozen fruit may also be effective but the DNA quality can vary. It is very important to minimize any unnecessary thaws when handling frozen fruit.
            - Sturdy frozen fruit that does not require additional chopping, such as blueberries and cherries (plus frozen cherries are pre-pitted!) work best. Delicate fruits (e.g., raspberries) may arrive damaged.
2. Prepare ingredients for visitor use.
    - Cut or portion fruits into pieces of approximately 2-4 cubic centimeters.
    - Distribute individually-sized portions of fruit into separate snack-size baggies.
        - If preparing fresh fruit in bulk, individually-portioning it prior to freezing helps to avoid unnecessary future freeze-thaws.
        - If preparing frozen fruit in bulk, try to minimize thawing during this step.
    - Fruit baggies are ready to use directly in the first step of the visitor-facing activity.
        - Use them immediately or freeze for future sessions.

Technical Tip: Amount of Fruit to Use

Larger pieces of fruit will yield more total DNA but may change the balance of the experiment. Excess fruit can require more lysis buffer to achieve a liquid consistency. Too much DNA can interfere with ink absorption into the marker. If adjusting the volume of fruit substantially from the protocol above, other reaction volumes may need to be adjusted to match.

Preparing DNA Extraction Reagents

Materials

Reusable Equipment	
Item	**Notes**
Scale	Should measure in grams
Dropper bottles	For 95% alcohol
Test tubes	Tubes should hold at least 15 ml

Consumable Supplies	
Item	**Notes**
Dish soap	
Salt	Can use commercial kitchen salt or lab-grade NaCl
95% alcohol	Can use ethanol or isopropanol

Procedures

1. Make a stock of lysis buffer solution.
    - Combine 25 ml dish soap and 3.5 g salt in a container.
    - Add water to bring it to 1000 mL.
    - Mix well.
2. Prepare reagents for visitor use.
    - Aliquot 5-8 mL of stock buffer solution into individual test tubes (1 per visitor).
    - Refill alcohol dropper bottles as needed.

Common Backend Questions

Standard operating procedures for this activity will vary based on the unique context of a given institution. Factors such as physical spaces, programming frequency, equipment availability, staffing models, and audience characteristics will introduce constraints and preferences that the general procedures above can be adapted to accommodate. Below are answers to the most common operational questions and insights from our experience running the activity in the Biotinkering Lab.

Question	Information
Can I use other types of fruit or vegetables?	*Sure, feel free to try other things! Success may vary.* While all living things have DNA, it may be easier to retrieve high volumes of intact material from some sources compared to others. Some sources of DNA may need to be treated differently (especially if not “squishable”), which could change the balance of the activity. We recommend avoiding processed foods (less likely to have intact DNA) and testing new materials ahead of time.
What are your favorite fruits?	*Strawberries, tomatoes, bananas, and kiwis.* Strawberries give a visible product practically 100% of the time. We have found tomatoes, bananas, and kiwis to be highly successful as well, ranging from 85-95% rates of visible DNA.
Are there any fruits you *wouldn’t* recommend?	*We didn’t have great success with pineapple or pomegranate seeds.* Store-bought frozen pomegranate seeds didn’t work for us. We initially had some success with pineapple, but found it to be very hit or miss. Some fresh pineapple worked okay, but other batches failed the majority of the time.
What about portioning fruit using other containers?	*Sure! Use whatever works for your space.* We portion pre-cut fruit into small baggies because this lets us prepare hundreds of portions in advance and use that same container in the first step of the activity (squish fruit). Other methods we have tried required additional supplies and facilitator guidance within the activity. As a bonus, visitors of all ages love the tactile experience of squishing their fruit.

How do you prepare your fruit in bulk?	*Buy fresh, cut to size and freeze, then distribute in batches.* We typically buy bulk fresh fruit, cut it to the desired size, and freeze on a tray in a single layer in a -80 deep freezer. Once frozen, we transfer the fruit to a large zipper baggie for long-term storage. We then typically prepare 200-300 single-use activity baggies at a time, labeling with stickers ahead of time and working quickly in small batches to prevent thawing. We then keep a few dozen baggies in a regular freezer for activity facilitators to access as needed.
How long can fruit be frozen?	*It depends on your freezer.* Consumer-grade freezers have regular defrost cycles, which will degrade DNA quality over time (and refreeze fruit into a solid mass that is difficult to use!). Even just a few freeze-thaw cycles can negatively impact results.
Can thawed fruit be refrozen?	*Maybe once or twice, but try not to do this too often.* As we have noticed significant decreases in quality with even a small number of thaws and refreezes, we are very careful to minimize this and try to not thaw fruits at all during preparation. Floor facilitators mark any baggies that were thawed and unused during the activity that day, so that they are used first next time. We throw out fruits that have been thawed twice.
What marker kits do you use?	*We designed this activity with the Crayola Mini Neon Marker Kit.* Unfortunately, these were discontinued in 2018! We recommend choosing a different kit that works for your space and budget. You could alternatively drop the markers altogether and choose to focus on making watercolor paints. We've also seen some people choose to carefully inject DNA into traditional pens with a syringe, though that may only be appropriate for older audiences.

Supplemental Resources

Full Materials List and Recommendations from The Tech

Reusable Equipment		
Item	**Notes**	**Specific Recommendations**
Freezer	Lab-grade is ideal as consumer-grade freezers usually have regular defrost cycles so fruit does not last very long	We store frozen fruit long term in a -80 deep freezer and restock a regular freezer as needed for daily activity use.
Knife	To prepare the fruit.	
Cutting Board	To prepare the fruit.	
Scale	Should measure in grams	
Dropper bottles	For 95% alcohol	We use McMaster-Carr 4 oz dropper squeeze bottles.
Tube racks	To hold each visitor's individual supplies	We use Celltreat multi-purpose centrifuge racks, which can hold varying sizes of tubes.
Test tubes	Tubes should hold at least 15 ml.	We use 15 ml plastic centrifuge tubes.
Small tubes	To mix the DNA and ink.	We use 2 ml Eppendorf tubes, as they have a flat bottom that maximizes ink absorption.
Scoops	To move the precipitated DNA.	We use standard lab spatulas.
Funnels	For liquid transfer	We use mini plastic funnels.
Containers	To act as tabletop trash bins and collect reusable supplies	

Consumable Supplies		
Item	**Notes**	**Specific Recommendations**
Fruits	Provide several options - berries, bananas, tomatoes, and kiwis all work well	Strawberries, bananas, kiwis, and tomatoes are our top performers. Other berries also work well and mangoes are a visitor favorite.
Baggies	To store fruit and provide an easy way to squish it	We use sealable, snack-size compostable baggies.

Labels	Optional but recommended if baggies with fruit are opaque	We use 1” round Avery UltraDuty GHS Labels, as they hold up well to freezing.
95% alcohol	Can use ethanol or isopropanol	We use isopropanol.
Soap	For the lysis buffer	We use Dawn dish soap.
Salt	Can use commercial kitchen salt or lab-grade NaCl	We use Morton table salt.
Marker kits	Any kind that uses liquid inks	We used Crayola Mini Neon Marker Kits, although those are no longer being produced.
Paper		We use quarter sheets with a printed prompt.