LEMELSON-MIT
# InvenTeams


# EDUCATOR GUIDE

Created with beyondbenign
green chemistry education

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# INTRODUCTION TO JV INVENTEAMS

**Welcome to JV InvenTeams, where students develop skills in science, technology, engineering, and math (STEM) through fun, invention-based design activities and challenges.**

## ABOUT LEMELSON-MIT

The Lemelson-MIT Program (**https://lemelson.mit.edu**) is dedicated to honoring those who have helped improve our lives through invention. The Program was established in 1994 at the Massachusetts Institute of Technology (MIT), by one of the world's most prolific inventors, Jerome Lemelson (1923 -1997), and his wife, Dorothy. It is funded by The Lemelson Foundation and administered by MIT's School of Engineering. The Lemelson-MIT Program recognizes outstanding inventors, encourages sustainable new solutions to real-world problems, and enables and inspires young people to pursue creative lives and careers through invention.

The Lemelson-MIT Program encourages great inventors through various outreach programs such as InvenTeams (**https://lemelson.mit.edu/inventeams**), a national grants initiative for inventive high school students who have a strong foundation in scientific and technical skills. InvenTeams are teams of high school students, teachers, and mentors that receive grants of up to $10,000 to invent technological solutions to real-world problems. The Lemelson-MIT Program developed JV InvenTeams in order to reach slightly younger high school students and provide them an introduction to inventive thinking and doing.

### About JV InvenTeams

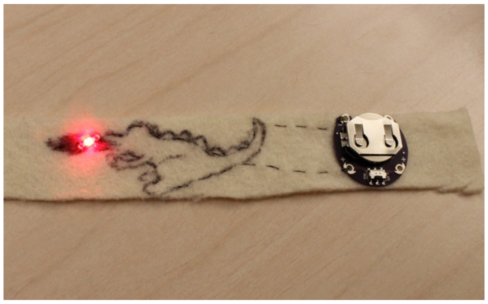
The goal of JV InvenTeams is to cultivate new ways of thinking and develop technical skills for students with limited access to hands-on STEM enrichment opportunities. Through prescribed activities, students will add to their own "toolkits" of minds-on knowledge and hands-on skills while having fun!

Students will learn how to identify a need in their lives or in the world around them and to develop their own invention after completing the main activity in each unit. They will pull from their expanding toolkit to come up with solutions.

## JV INVENTEAM ACTIVITY GUIDE COMPONENTS

Each unit of JV InvenTeams activities is presented in the same format. The Educator Guide includes specific notes and segments, while the student version is more streamlined and includes working space for the students. The educator may decide how much of the information should be shared with the students and in what manner – e.g., read out loud or individually. Each meeting within the unit is estimated to take between 1.5 and 2 hours to complete.

Each group of young people will be different, so the pace of each unit is up to the educator. Know that there are numerous resources to balance the unit to meet your needs. Some may find that breaking units into a couple of sessions will allow the think-time needed for your group. Others may want to streamline items and skip some of the videos.




**Each unit has the following in the first pages:**

- Title page with summary of **the** unit and learning objectives
- Summary of each meeting within the unit
- Master consumable materials and tools lists

**Each meeting within the unit includes the following:**

- "Lab coat" of hands-on and minds-on skills to be learned
- List of tools and materials
- Procedure
- Key terms
- Safety message(s)
- Video clips
- Instructions with step-by-step procedural notes
- Pop-outs that include any of the following: historical connections, Inventor/Invention Spotlights, related patents, Extend the Learning, High School Connections, and College Connections
- Indicators of a successful meeting
- Student Self-Assessments as exit slips

## KEY TERMS

**Cold (n)**: The absence of heat energy; "coldness" is a subjective term that refers to people's perception of low temperature, or low heat energy.

**Conduction (n):** The transfer of heat within an object or between objects in contact with each other.

**SAFETY**

Wear protective gloves and safety glasses for this activity. Avoid breathing in the release agent spray. Use it in a well ventilated room or outdoors.

**INVENTOR SPOTLIGHT**

In 1902, mechanical engineer Willis Carrier patented the air conditioner, a device he originally invented to solve a problem facing a paper printing plant in Brooklyn, New York. Read more about his invention—and how the invention of air conditioning helped expand Southern cities such as Houston and Atlanta.

**You may ask, “Why should I invent?” Here are some of the reasons you can share during the first meeting. Invention…**

- solves world problems like finding clean sources of energy and treating unsafe water;
- helps people;
- allows people to explore a creative process that often involves teamwork;
- provides fulfilling careers: inventors are often scientists and engineers who improve areas of health, energy, food and transportation;
- can also lead to a high-paying career with many job opportunities as an engineer or scientist; and
- is fun!

## GROUP SIZE

JV InvenTeams is recommended for approximately 20 students in Grades 7, 8, 9 and 10. Most activities require students to work in teams of four.

## PARTNERSHIPS

The Lemelson-MIT Program encourages participating schools to seek community partnerships to sustain JV InvenTeams. Partnership opportunities include:

- Science and technology museums, to provide direct mentoring;
- Local technology and engineering companies, to provide funding for future extension ideas, materials, or mentors;
- Local universities or colleges, to provide collegiate mentors; and
- Hardware stores, to provide tools or materials.

## FLEXIBILITY

JV InvenTeams has built flexibility into the program to meet the needs of educators, school systems, and grants-based clubs and organizations.

Following are some examples:

- Each unit is designed to stand on its own. Educators can lead one unit, a few units or all of the units.
- The program can be held in any educational setting with a science or technology educator facilitatating the activities.
- Each unit has approximately 6 meetings of 1.5 - 2 hours duration.
- Meetings can take place multiple times a week or once a week.

## INVENTIVE THINKING

Both educators and students will develop an understanding of the invention process as you navigate through JV InvenTeams. This new way of thinking, part of the minds-on toolkit, may take some time to adopt since learning within the school day increasingly focuses on standardized tests of academic knowledge. Invention is a variable, non-linear process. JV InvenTeams introduces the curiosity and creativity of recognizing problems and addressing them with novel solutions. You will not need to worry about knowing the "right" answer since there are countless possibilities. Experiencing failure is part of the invention process.

Inventing is creating something new that is useful or helpful, by means of one's own investigation, experimentation, and thinking. An invention is the product of the inventing process. It can be a device, a material, a system, and even a plant. Invention refers to a new physical thing made possible by technology for the purposes of JV InvenTeams. Inventive thinking challenges what people come to expect or anticipate. Revolutionary inventions, known as macro-inventions, make a huge impact on the way we live. Examples include the internal-combustion engine for the automobile and the integrated circuit for consumer electronics. Most inventions are micro-inventions, or adaptations that grow from larger-scale inventions. This means making an existing product faster, stronger, cheaper, easier, safer, more efficient, or more useful.

### User-Centric

The key to inventing is to make sure the invention is user-centric. This means that students need to think about and understand problems affecting real people and their specific needs. Researching the unique characteristics and needs of the user is essential to coming up with an effective design – as is working directly with them! Students will develop empathy for the beneficiary during the process.

An example of this would be a student noticing that his or her grandmother has difficulty moving around the house in her slippers, due to slippery floors.

The student should investigate by first asking his or her grandmother:

- Do you wish your slippers had a better grip?
- What parts of the slipper do you like? What parts would you change? Why?

After learning from the user, the student can further investigate.

Questions he or she might ask include the following:

- Does the solution lie in changing the floors or the footwear?

- How can I change her slippers to make the grip better?
- Is there another product on the market that provides the ease and comfort of slippers with the safety features of shoes with more grip?

These questions will inform research and allow the student to develop meaningful solutions.

## Deciding on a Good Problem to Solve

Identifying a good problem to solve can be challenging, but it is just like any other skill: it becomes easier with practice. Therefore, at the beginning of each unit in JV InvenTeams, students will be given a problem or scenario that requires devising an original solution. Coming up with solutions to problems can be difficult at first, but students will gain confidence in generating new ideas over time. One way to accomplish this is through transgressive thinking – applying flexible or "out of the box" thinking in one area to another. The SCAMPER technique is a good technique to start with because it provides a framework to come up with solutions.

## SCAMPER

The SCAMPER brainstorming technique was developed by Bob Eberle and published in a book by the same title. SCAMPER is based on the notion that something new can be modified from something that already exists. Each letter in the acronym represents a different way you can mentally view the characteristics of the challenge. It's a "mash-up" of disparate things to conceive something new.

**S** = **Substitute** *(playing basketball with a softball)*

**C** = **Combine** *(toothbrush combined with a pencil to create a new product)*

**A** = **Adapt** *(how would you eat your spaghetti without a utensil?)*

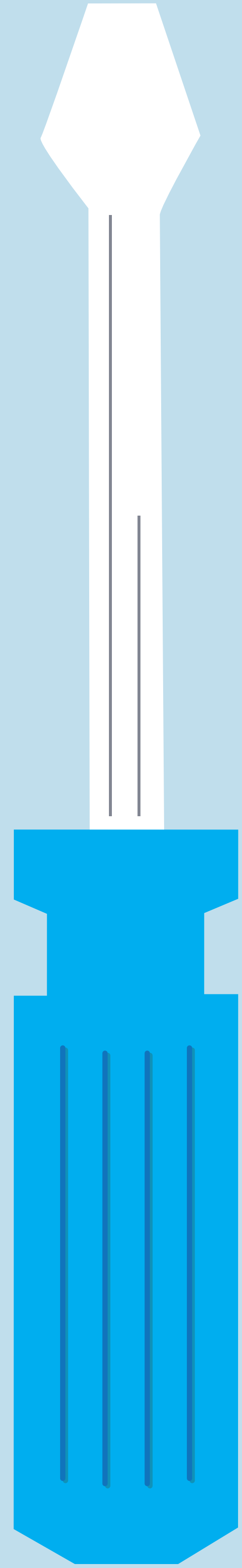
**M** = **Magnify** *(how would your chair function if its legs were wider and longer?)*

**P** = **Put to Other Uses** *(could your fork be used as a comb?)*

**E** = **Eliminate** *(could you play tennis without a racket?)*

**R** = **Rearrange** *(what if the laces of a shoe were placed on the bottom and not the top?)*

The SCAMPER technique involves the students first stating the problem they would like to solve, which defines the challenge. Then it's a matter of asking questions, using SCAMPER to guide the students. No idea is a "good" or "bad" idea at this point.



## DOCUMENTATION

Students should be encouraged to document their progress along the way. This includes saving sketches, designs, research data, graphs, images, and early prototypes. Most of this work, with the exception of the actual prototypes, can be compiled in the student guides. Students should routinely review their guide, adapting what they have learned and experienced to new challenges.

## PATENTS

Since this program is all about invention, it is important that educators and students familiarize themselves with the United States laws that protect the intellectual property of inventors.

A patent is one type of intellectual property that can be legally protected through the U.S. Patent and Trademark Office (USPTO). The other types of intellectual property are trademarks and copyrights. A trademark includes any word, name, or symbol used to distinguish one manufacturer from another (e.g., brand name). Copyrights are recorded with the U.S. Copyright Office in the Library of Congress for original authored works like books and music.

According to the U.S. Patent and Trademark Office, patents provide legal protection to inventors' intellectual property by excluding others from profiting from their property in the U.S. for a specific amount of time, in exchange for the inventors' disclosure of their idea according to the criteria for granting a patent. There are three different types of patents. Utility patents are granted to inventors who discover a new and useful process, machine, article of manufacture, or a new and useful improvement. Design patents are granted to those who invent a new, original, and ornamental design for an article of manufacture. Finally, a plant patent is granted to an inventor who invents a new variety of plant. The basic components of a U.S. patent are: patent number, title, inventors, assignee (optional transfer of intellectual property to a company or other individual), abstract (short overview of invention), drawings, description (technical details), and claims (legal information). To learn more about the patent process, visit: **http://uspto.gov/**. Students will be required to search patents to ensure that their idea is unique. Patent searches can be done through Google Patents and Free Patents Online. Both have easier search functions than the U.S. Patent and Trademark Office.

Jerome Lemelson, founder of The Lemelson Foundation, had a productive life as an inventor, holding more than 600 patents. He was awarded his first patent in 1953 for a toy cap, and spent the next 45 years coming up with inventions that led to products such as bar code readers, automatic teller machines, cordless phones, cassette players, fax machines, machine vision, and personal computers.

It is important to keep in mind that not all inventions are patented. Some inventors purposefully do not seek a patent with the idea that their inventions are immediately and widely available. An example is open source software, which allows anyone to use the software without paying a fee.

This openness can spur further invention since anyone can access it and make adaptations. In spite of the changes in patent law through the Innovation Act of 2013, students should adopt the habit of recording and dating their work, including early sketches and research. This practice will be useful for future science exploration and invention.

## FACILITATION TIPS

### Word Wall

Consider using the Key Terms to construct a word wall. Use the Word Wall to help young inventors review what was covered in the previous session, reinforce concepts that may need some review, and reinforce the use of new words to promote vocabulary growth.

### Idea Board

Consider creating an Idea Board out of poster board that serves as a repository of new ideas and questions. Students can post new invention ideas here, which can be referenced for the development of their inventions at the end of the unit.

### Teamwork

Students will be working in teams throughout this program. Consider inviting a coach from one of your school's sports programs to talk about how important teamwork is, on and off the field.

### Facilitating Redesign

Encourage students to improve only what needs improving. It is a natural impulse to want to throw away an entire design idea because one element of it needs improvement. Encourage students to think hard about what elements of their design work well and what elements they want to improve. Help them narrow their redesigned focus so they are truly improving specific elements of their original design as opposed to starting from scratch.

Encourage students to learn from the work of others before implementing improvements. Engineers and inventors always learn from the work other people have done! Have students do some research on new checknologies before deciding on their improvements. Encourage students to link their improvement ideas to specific information they learned in their research. Help students share their work with others so that everyone can utilize the strengths found in each design.

Have students predict how their results might change based on the improvements they made *before testing*. Students will likely have lots of ideas about how their second prototype will perform as compared to their first prototype. Allow students to explain what they think will happen and why. Encourage students to apply their understanding of new hands-on skills and minds-on knowledge.

Have students reflect on the strengths and weaknesses of their second prototype *after testing*. Encourage students to identify what worked well and what did not work well in their second design. Have students brainstorm further improvements and justify their ideas with evidence from their previous tests. Tell students that inventors often repeat this process of prototyping and testing many, many times before releasing a final design!

# UNIT SUMMARY FOR EDUCATOR

Students will develop sustainable bioplastic prototypes made from benign materials in this Green Chemistry unit. They will learn about the life cycle of conventional petroleum-based plastics and consider how each stage of the life cycle could be improved upon to make the process more sustainable. Students will learn about the role that Green Chemistry plays in intentionally designing chemical products that are safer for humans and the environment. During their various trials, students will experimentally determine the role that the concentration and pH of a solution play in breaking down a starch into polymers and monomers. They will also learn how the type and size of starch granules influence the flexibility of your bioplastic. Students employ these chemistry principles to optimize their bioplastic formulation to create alternatives to plastics currently in use. They will consider improvements on the design as part of the prototyping process.

Students will gain both minds-on and hands-on skills in Green Chemistry to expand their toolkit. Minds-on skills include understanding the role of inventing in Green Chemistry, describing chemical reactions, creating a product procedure, and communicating with others about their invention. Hands-on skills include measuring wet and dry materials, safely handling benign materials, and formulating and optimizing bioplastics. Students will learn what it means to be inventive thinkers and will practice inventive thinking as they progress through the unit.

## LEARNING PRINCIPLES

- Green Chemistry
- Chemical reactions
- Laboratory safety
- Prototyping

# MEETING SYNOPSES

## 1 Invention Introduction

Students do warm-up activities and discuss invention. Students play “Four Corners” to help the educator assign diverse teams.

## 2 Inventing for a Sustainable Future

Students learn about laboratory safety, inventing, and Green Chemistry. Students create benign lava lamps that use nontoxic materials that easily decompose.

## 3 Reuse and Explore

Students demonstrate an understanding of how plastics are produced when a starch is heated in the presence of an acid. Students reuse, experiment, and test the components of their benign lava lamp to examine the properties of a bioplastic in different environments.

## 4 Experimenting with Bioplastics

Students will comply with laboratory safety procedures to create bioplastics, compare their properties, and identify properties needed for their unique bioplastic prototype.

## 5 Optimizing Our Bioplastic Invention

Students will examine the role that concentration and pH of the solution play in the properties of a bioplastic. Students use their knowledge of bioplastic properties to brainstorm ideas for a prototype.

## 6 Prototype

Students optimize the bioplastic-making process to create a unique bioplastic with specific properties needed to create their prototype. Students will then write a pitch to communicate about their invention.

## 7 Communicating Ideas

Students communicate a purposeful invention that uses their new minds-on and hands-on skills from Green Chemistry.

## STUDENT SELF-ASSESSMENT: GREEN CHEMISTRY

Inventors need to be confident and know their own strengths and weaknesses. Use this table to think about how likely you are to complete these skills with confidence. Check the response that best describes your confidence right now.

| I can… | Probably | Maybe with help | Probably not |
|---|---|---|---|
| Work safely in a chemistry lab. | | | |
| Measure wet and dry materials. | | | |
| Safely use laboratory equipment like a hot plate, beakers, and stirring rods. | | | |
| Work as part of a team. | | | |
| Design experiments. | | | |
| Make products friendlier or greener for the environment. | | | |
| Identify a real-world problem to solve and apply my skills to solve a real-world need. | | | |

# Today

Which skill was the most challenging?

___________________________________

Which skill was the most enjoyable?

___________________________________

# In the Future

What will YOU invent?

___________________________________

How is it unique?

___________________________________

How is it useful?

___________________________________

## PROBLEM STRIPS

Copy and cut out these Problem Strips prior to leading the Invention Introduction with students.

**You want to eat soup but you don’t have a spoon.**

**You need to walk across a hot concrete parking lot after going to the beach.**

**You hit a baseball over a barbed-wire fence and need to get it back.**

**There is a fly buzzing in your room.**

**You lost an item under your heavy dresser and want to get it back.**

Post these safety rules at the start of Meeting 1 and keep them posted throughout the unit.

**SAFETY**

1. **Always get your teacher's approval before conducting a lab. Never experiment on your own.**
2. **Always wear safety gloves and goggles during labs from pre-lab setup to post-lab cleanup, or when your instructor tells you to do so.**
3. **Read and follow all warning labels on substances being used.**
4. **Be sure your teacher is aware of any allergies you may have.**
5. **Carefully follow all instructions when conducting a science activity.**
6. **Keep all materials used in the science activity away from your mouth, nose, and eyes.**
7. **Do not place your hands on your face when conducting—or cleaning after—an activity.**
8. **Never taste anything during a science activity.**
9. **Tie back long hair, and secure loose clothing and dangling jewelry.**
10. **Safety equipment must remain in good working condition. Do not play with it.**
11. **Tell your teacher immediately if an injury, spill, or other accident occurs.**
12. **Clean up your work area after conducting a science activity.**
13. **Wash your hands with soap and water after completing a science activity.**

# BIOPLASTIC REFERENCE SHEET

| STARCH | GRANULE SIZE |
|---|---|
| Rice | 2 microns |
| Corn | 3-8 microns |
| Tapioca | 5-30 microns |
| Potato | 100 microns etc. |

## BIOPLASTIC FORMULATION

starch
2 tsp
+
additive
1 tsp

mix

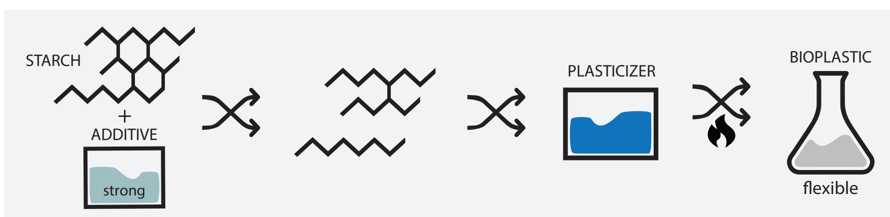
water
2 tsp

mix

plasticizer
2 tsp

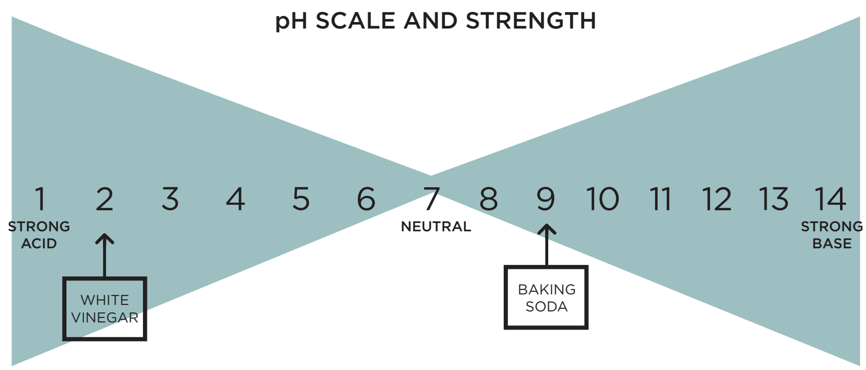
mix

product





### pH SCALE AND STRENGTH



## KEY TERMS

**Engineering (n)**: using science and technology to design and improve objects and systems to solve a problem or meet a need.

**Invention (n):** a unique and useful device or process.

**Iteration (n):** a version of a design in a series of designs.

**Modification (n):** the act of making small or partial changes.

**Patent (n):** an intellectual property right issued by the U.S. Patent and Trademark Office, excluding others from making or selling the **invention** in the U.S. for a specified period of time in exchange for disclosing the **invention**


## Tools

- Writing utensils
- Utility knives or sharp scissors
- Projector and computer to show video

## Materials

- Student guides
- Tape
- Cardboard and scrap materials from the recycling bin
- Problem Strips
- Self-Assessments

## Procedure

- Distribute Guides and Introduce JV InvenTeams
- Introduction to **Invention** and Problem Solving
- Design a Cell Phone Stand
- Watch Some **Invention** Videos
- Research an **Invention**
- Discuss Improvements to an **Invention**
- Investigate Real-World Improvements
- Watch Videos about the Design Process
- Set Rules and Develop Teams
- Self-Assessment

## Distribute Guides and Introduce JV InvenTeams

1. Let students know that today they will learn about the basics of invention. Get everyone thinking about invention by asking:
   - How would you define "invention?"
   - Why do you think people invent things?
2. Distribute one JV InvenTeams guide to each student. Tell students that their **invention** guides will be a portfolio of their work. Explain that the grid paper and blank paper at the end of each meeting can be used to sketch, brainstorm, and document ideas.

## INTRODUCTION TO INVENTION AND PROBLEM SOLVING

1. Tell students that we all run into challenges on a daily basis. They will now get a taste of what being an inventor means by coming up with ideas to address some of these problems.
2. Divide students into teams of 3 or 4 and give each team a Problem Strip you prepared.
3. Have teams devise a quick **invention** that solves their problem by using materials from the recycle bin.
4. Bring everyone back together and have teams take turns sharing their solutions. To facilitate sharing, students can ask the following:
   - What else would you do if you had more time?
   - What would you add or change if you had more expensive supplies?
5. Explain that inventors often use inexpensive, everyday materials to create prototypes of their **inventions**. That's because they don't want to waste expensive materials in the early stages of designing. Failure and mistakes are common and part of the process.


*Early prototypes of the Polaroid camera from the MIT Museum collection*

MEETING 1

**PhD (n):** a postgraduate academic degree awarded by universities.

**Prototype (n):** a model of something built to test a concept. Many iterations are created before the final design is determined.

### EDUCATOR NOTE

Consider constructing a Word Wall with these Key Terms to help young inventors review what was covered in the previous session, reinforce concepts that may need some review, and reinforce the use of new words to promote vocabulary growth.

### MIT MOTTO "HANDS-ON AND MINDS-ON"

MIT's motto is Mens et Manus, which translates to Mind and Hand. Inventors are resourceful and use many tools. Some "tools" are based on learned knowledge stored in our minds from science and math classes. Other "tools" are practiced – hands-on skills like drawing and building things.

## EDUCATOR NOTE

The cell phone activity could take even longer if students get invested. Consider breaking this meeting into two sessions if you want to take your time.

## EDUCATOR NOTE

**After Cell Phone Stand**

It is beneficial for students to conduct some peer evaluation if you have extra time. Have students leave their finished cell phone holders on their table tops. Leave a blank piece of paper and pen next to each stand. Students can walk around the room and anonymously leave some constructive feedback. A few students can share their feedback and explain how they would improve their project.

# DESIGN A CELL PHONE STAND

*1.* Ask students if they ever get annoyed by phones not being able to stand up on their own. Explain that inventors think outside of the box and often create prototypes of their ideas using everyday materials.

*2.* Tell students that their challenge is to invent a low-cost cell phone stand using recycled materials like cardb and tape.

*3.* Before students start, have them watch **Josh Ramos' Cardboard Videos** to learn some cardboard cutting tips and tricks. Josh earned his PhD in Mechanical Engineering from MIT in 2018.

*4.* If students are having difficulty coming up with their own design, they can check out **Josh Ramos' Cardboard Phone Stand**.

*5.* When finished, have students respond to the Follow-Up Questions (listed below) in their guides.

- What do you like about the stand you made
- How would you change your design if you wanted to watch a video in the landscape format (sideways)?
- Where are the speakers on your phone? How might you use the placement of the cardboard or other materials to improve the sound?

6. Share your design with another student.

*7.* How would you incorporate your comments and theirs in your next design? Describe this next design iteration in words or pictures.

*8.* Tell students that during the JV InvenTeams initiative, they will learn about new tools and materials through invention activities like this one. They will think of **iterations** to improve or change their designs, after successfully meeting these challenges.

**SAFETY**

Watch **Josh Ramos' Cardboard Videos** to learn how to safely bend and cut cardboard before doing the activity.

## WATCH SOME INVENTION VIDEOS

1. Explain that each year, teams of undergraduate students and graduate students apply for the Lemelson-MIT Student Prize.

   Have students check out some cool videos from previous winners and finalists on the **Lemelson-MIT Program's** website.

   - **Julie Bliss Mullen's invention brings clean water to people everywhere** (2:00)
   - **Chen Wang, Chandani Doshi, Grace Li, Jessica Shi, Charlene Xia, Tania Yu's invention makes life easier for the blind** (2:30)
   - **Ramesh Raskar's inventions improve people's lives** (4:06)

2. Explain that all good inventions, including the ones presented in these videos, stem from a real problem or need. Most inventions do not produce radical change in society, but rather build upon previous inventions to make aspects of life easier, safer, more comfortable, more engaging, and/or healthier.

## RESEARCH AN INVENTION

1. Have students identify an object in the room. Ideas include a specific type of desk, piece of technology, chair, tool, writing utensil, or article of clothing.

2. Explain that we often take the daily products and tools in our world for granted. Each of these items has a history of evolution. Scientists, engineers, and designers made **modifications** over time that produced the modern product you see today.

3. Tell students that they will conduct research on inventions using **Google Patent Search.** Explain that Google Patents list U.S. patents as well as international patents. Patents are sequentially numbered; for example, search for "student desk" and look at the images for US7571959B2.

4. Give students a few minutes to conduct research on the product they identified.

5. How can this product continue to improve?

6. What information can you gather from the technical drawings?

7. Why are detailed images such an important part of a patent?



### EDUCATOR NOTE

**After Videos: Debrief**

Engage students in a discussion about the videos. Students should be asked to think and converse about the common themes, the inventors' approach, and why failure during the process is expected.

**INVENTOR SPOTLIGHT**

**MIT alumna Alison Wong invented Keyprop™, a simple solution to the problem of keeping your smart phone propped up. Check out a video of her invention: Invention Profile: Keyprop.**

## DISCUSS IMPROVEMENTS TO AN INVENTION

1. Have students work in small groups to brainstorm how they could improve one product or process they use during a typical day. Students will respond to the following prompts in their guide:

   - How might you go about making the improvement? Describe your process.
   - What might be some challenges to meeting this need?
   - Thinking further, do you notice anyone in your family or community who struggles to complete a certain task? What invention might improve this aspect of their life?

2. Tell students they will learn to carefully observe the world around them in search of problems that can be addressed with a technological solution.

## INVESTIGATE REAL-WORLD IMPROVEMENTS

- **Sesame Ring**: Several MIT undergraduate students were having difficulty locating their reusable train tickets upon entering the train station. Their solution is a wearable reader in the form of a customizable ring.
- **Tile**: Do you ever have difficulty finding your keys or wallet in your home? The solution is a small piece of plastic with a chip that connects to an application on your smart phone.
- **uBeam**: Meredith Perry, a graduate of the University of Pennsylvania, was sick of long electrical wires for laptop computers. She started a company, uBeam, that is working on a wireless charger.

**EXTEND THE LEARNING**

You can continue exploring invention by researching well-known inventors in your community. How? Go to **Free Patents Online.** The login is free. Click on the SEARCH tab, then use the "Quick Search" feature to enter your location under "Inventor Fields." You may want to search chronologically by the last 20 years.

### EDUCATOR NOTE

**Before Product Discussion**

Ask students in small teams or as a class to devise a list of problems or things that don't work quite right in their daily lives. Give them a few examples to help them get started, such as a grandparent slips walking in socks, their laptop computer wires get tangled up, and they can't wake up to an alarm.

### EDUCATOR NOTE

**Before Real-World Examples**

Explain to the students that invention follows a process of identifying needs, brainstorming ideas, sketching, building a prototype, testing, modifying, and re-testing. Potential users are consulted for feedback throughout the process.

## WATCH VIDEOS ABOUT THE DESIGN PROCESS

1. Have students watch the **MIT Design Process Videos**. The videos cover: Design Introduction, Observation, Brainstorming, Idea Selection, and Prototyping.

2. Give students time to outline the design process in their guides.

## SET RULES AND DEVELOP TEAMS

1. Tell students that JV InvenTeams is all about hands-on fun. To make this possible, here are a few important rules to follow:

   - Safety is the number one priority! Watch tutorial videos before using new tools and materials.
   - Ask for help. Don't guess, especially about how a tool works.
   - Consider all ideas. No idea is "dumb." As an inventor, focus on the ideas with the most potential when developing a prototype.
   - Embrace failure. Failure is a part of the invention process!
   - Value your team. Everyone brings different skill sets and knowledge to the table.

2. Explain that most of the projects require working in small teams. Diverse teams are successful teams.

3. Use the directions on the next page to play "Four Corners." This game will help you place students into diverse teams.

## SELF-ASSESSMENT

Collect the completed self-assessments as exit slips when students leave.

## INDICATORS OF A SUCCESSFUL MEETING

Students can build a cardboard cell phone stand, can demonstrate how to think like an inventor, and understand how the design process works.

MEETING 1

### EDUCATOR NOTE

**After Design Process Videos**

Ask a volunteer to recap the steps of the design process. Have them draw a visual outline to include on the Idea Board. Survey the students to see if they have any questions before proceeding.

Steps of the design process are:

- identifying needs,
- brainstorming ideas,
- sketching,
- building a prototype,
- testing,
- modifying, and
- re-testing.

**Before Setting Rules**

You can create a bold list of these rules to place on the Idea Board or somewhere else that is visible in the classroom.

## FOUR CORNERS GAME FOR GREEN CHEMISTRY

**Teams of inventors include people with different interests and skills. Ask students to think about their own interests and skills to help you organize the class into diverse teams. Have students draw a line from each type of team member on the left to the best-matching description on the right.**

### Types of Team Members

**Formulator**: I like to measure and mix things up.

**Talker**: I like to talk to people and I enjoy public speaking.

**Doodler**: I like to draw things and express my thoughts through drawing.

**Organizer**: I like to organize people and things.

### Your Interests and Skills

Sounds most like me

Sounds almost like me

Sounds a little like me

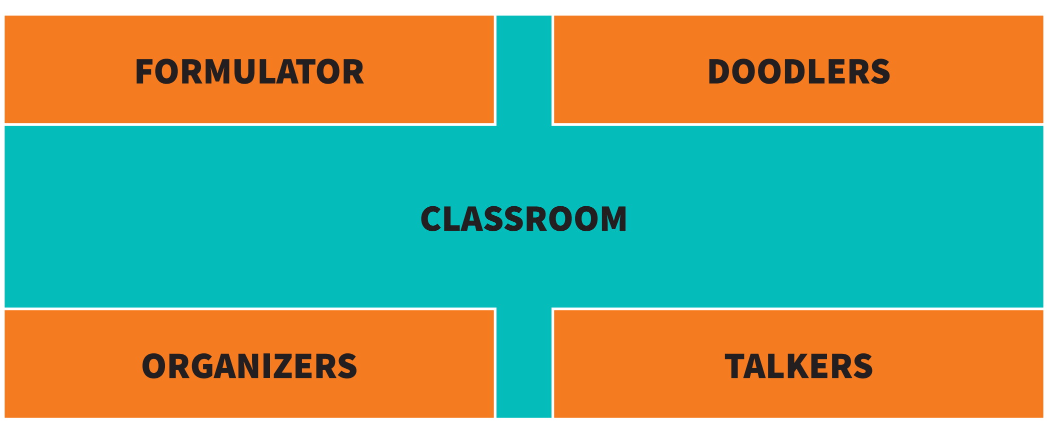
Sounds least like me

The corners of your classroom will be marked with the four types of team members. Which corner best matches the interests and skills of each student.

## EDUCATOR NOTE

Ask students to go to their respective corners based on their "sounds most like me" description. The corners will have an equal number of students in an ideal world. If they don't, mention to the students that equal numbers are needed in order to make well-balanced teams. Have students in the larger group(s) look at their "sounds almost like me" description and compare with the corners needing students. Ask students to consider rearranging.

Have students count off within their corners once each has a nearly equal number of students. Finally, have all 1s, 2s, 3s, and 4s come together to form their invention teams. Write down the names and teams in your notes. These teams will come into action when students start designing in teams.



# MY NOTES

### KEY TERMS

**Benign (n):** not harmful in effect.

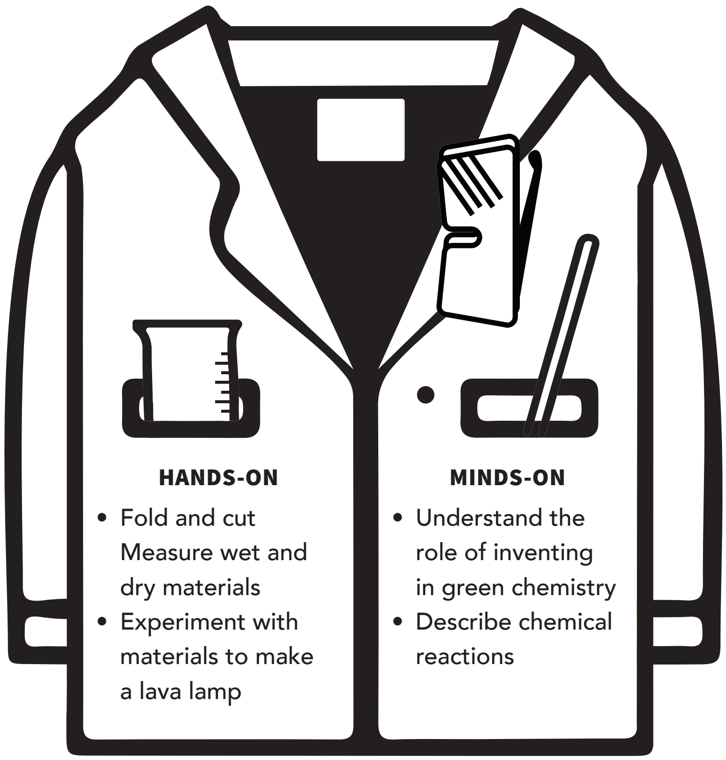
**Chemical reaction (n):** a change in which new substances (products) form from starting materials (reactants).

**Density (n):** the mass of a substance per unit of volume.

**Design flaw (n):** a design that fails to meet requirements or to serve customer needs.

**Green chemistry (n):** the design of chemical products or processes that reduce and/or eliminate the use or generation of hazardous substances.

**Heterogenous mixture (n):** a mixture that has two or more phases with different properties; a suspension.




## TOOLS AND LAB EQUIPMENT

- 250-**mL** glass beaker, 2 per student group
- 400-**mL** (12 oz.) glass bottle, 1 per student group
- Aluminum tray, 1 per student group
- Stirring rod, 1 per student group
- Teaspoon (tsp.) measure, 1 per student group

## MATERIALS AND LAB SUPPLIES

- Wax pencil, 1 per student group
- Protective gloves, 1 pair per student
- Protective goggles, 1 per student
- Student Guides, 1 per student
- Lab Safety Rules
- Baking soda
- Guar gum (a flour substitute)
- Natural food coloring
- Vegetable oil
- White vinegar

MEETING 2

## PROCEDURE

This meeting will cover laboratory safety, inventing, inventing green, and making lava lamps.

- Why Invent with **Green Chemistry?**
- Pre-Lab: Inventing with Intention
- Introduction to Lab Safety
- Lab Preparations
- Lab: Make a Greener Lava Lamp
- Post-Lab Cleanup
- Reflection: **Green Chemistry** Invention
- Journal Log
- Self-Assessments
- Indicators of a Successful Meeting

**Homogenous mixture (n):** a mixture that has only one phase and has uniform properties throughout.

**mL (n):** abbreviation for a unit of capacity: milliliter, or 1/1000 of a liter.

**Solution (n):** the mixture of two or more substances.

**Viscous (adj):** holding together in a thick, sticky way.

## WHY INVENT WITH GREEN CHEMISTRY?

**Green chemistry** is the science of designing chemical products or processes to reduce and/or eliminate the use or generation of hazardous substances. Different from other sciences that study what something does, **green chemistry** focuses on the building blocks of a product to make it more environmentally friendly. John Warner, co-founder of the field of **green chemistry**, invents sustainable solutions to hazardous materials through chemistry. He has 187 molecular design patents and inventions to his name. He started the Warner Babcock Institute for **Green Chemistry** and leads a team of green chemists in developing green technology at the molecular level.

Listen to why John thinks inventing sustainably at the molecular level is important. **John Warner, Invention Education and Green Chemistry**.

## Why invent with green chemistry?

Want additional information on John

Warner? **Read his Inventor Profile here.**

## Questions for the Video:

1. List two examples of **green chemistry** inventions: (Answers in italics)

   a. *Low light solar technology: ability to use solar power in place of traditional sources*

   b. *Additive to pavement: reduce harmful chemicals in the process*

2. Chemistry is involved in what industries?

   a. *Designing and making clothing*

   b. *Materials in automobiles*

   c. *Materials in computers*

   d. *The way we grow plants for food*

3. What human and environmental impacts have these industries created and how?

   a. *By using harsh chemicals, they have made people sick and accelerated climate change.*

4. Why is there a need for sustainable invention?

   a. *Through learning science and invention, we can change how things are made and disposed of to help the health of both people and the environment.*

**I will make the green chemistry invention pledge to learn science to improve the way we make and do things for the health of both people and the environment.**

**X**______________________________________________

## PRE-LAB: INVENTING WITH INTENTION

Inventing for a sustainable future involves thinking about the environment at the earliest stage of design. The inventive mindset taps into the creativity and curiosity of inventors, artists, and scientists. Designing with the environment in mind involves thinking about the interaction of matter, also known as chemistry.

Chemistry consists of the fundamental makeup of all of the products we use and consume. However, chemistry sometimes has a negative reputation when it comes to the environment. There are a lot of products that have been created in a way that is hazardous, wasteful, and damaging to the environment.

**Green chemistry** is an approach that puts chemists in the role of the inventor. It helps them intentionally design chemical products that are safer for humans and the environment. **Green chemistry** is often described as the science of creating solutions and sustainable products. It focuses on reducing or eliminating pollution at the earliest design stage of a material, as well as in its use.

Green chemists keep in mind their invention's impact on both human and environmental health. They are inspired by nature since nature is able to "invent" without causing harm. The traditional lava lamp contained harmful chemicals that create toxic waste. Therefore, it needed to be re-invented to make a sustainable solution.

Behind every invention is a person or team of people who recognized a problem or an opportunity and invented a solution. The object of this experience is to apply inventing principles and infuse them with an understanding of **green chemistry.** Inventing is a balance between discovery and creativity. The intentional invention of materials that are "**benign** by design" is at the core of **green chemistry**.

Let's create a non-harmful, or **benign,** lava lamp by using nontoxic materials that will easily decompose. Looking at our starting materials, how do we know that they are safer for both us and the environment?

*The materials we are starting with are:*
*1) Baking soda, 2) Guar gum (a flour substitute), 3) Natural food coloring, 4) Vegetable oil, and 5) White vinegar. The Food and Drug Administration (FDA) recognizes all of these ingredients as safe for consumption. All of these chemicals are often used in cooking. Baking soda and vinegar are also used as green cleaning products.*

## INTRODUCTION TO LAB SAFETY

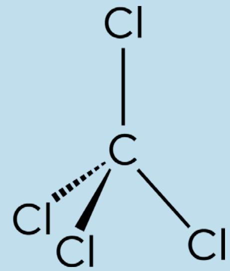
Discussing lab safety helps set the tone to introduce science experiments in the classroom. It introduces safe practices and helps your students understand why these practices are used. Refer to the best practices recommended by the American Chemical Society:

> Asking your students to help develop the rules may help with the ownership and understanding of the lab safety rules. You may also choose to set the rules. Either way, make sure students understand these rules and why they are necessary. You may choose to have students create posters for display in the room throughout the year to emphasize safety and remind students of the specific safety rules.

MEETING 2

### EDUCATOR NOTE

Review the Lab Safety Rules with your students before beginning an activity.




### EXTEND THE LEARNING

**Carbon tetrachloride, a liquid ingredient, was used in the formulation of very early lava lamps. It is a carcinogen, which is a substance capable of causing cancer in living tissue. Tetra is a prefix meaning "four" and chloride is a compound of chlorine.**

**The chlorine atoms in carbon tetrachloride are a different form and molecular structure, which can cause cancer in humans. Look at the image below to see its structure.**

**Learn more about how traditional Lava Lamps are made here.**

## SAFETY

1. Always get your teacher's approval before conducting a lab. Never experiment on your own.
2. Always wear safety gloves and goggles during labs from pre-lab setup to post-lab cleanup, or when your instructor tells you to do so.
3. Read and follow all warning labels on substances being used.
4. Be sure your teacher is aware of any allergies you may have.
5. Carefully follow all instructions when conducting a science activity.
6. Keep all materials used in the science activity away from your mouth, nose, and eyes.
7. Do not place your hands on your face when conducting—or cleaning after—an activity.
8. Never taste anything during a science activity.
9. Tie back long hair, and secure loose clothing and dangling jewelry.
10. Safety equipment must remain in good working condition. Do not play with it.
11. Tell your teacher immediately if an injury, spill, or other accident occurs.
12. Clean up your work area after conducting a science activity.
13. Wash your hands with soap and water after completing a science activity.

## LAB ROLES

Inventing with green chemistry is a team sport. Each person on a team has an important role with responsibilities. Suggested roles and responsibilities are:

**Formulator**—responsible for chemicals

**Talker**—responsible for reading the procedure and communicating results

**Doodler**—responsible for recording observations

**Organizer**—responsible for setting up all non-chemical materials and for cleaning up glassware

MEETING 2

## LAB PREPARATIONS

Before you begin, have students sign up for a role within their group for today. They can use the space in their Student Guides to note who will assume each role. With each lab activity, the roles within the group will change.

## REMINDERS

- Review the safety rules.
- Have students read through the lab before they start.
- Have students organize all of the materials they are going to need at their lab bench or station.
- Have students put on protective gloves and goggles before starting the lab.
- Have students pour any liquids over the aluminum tray.

### TIPS AND TRICKS

**Add the group's name to the tray.**

**Always label beakers and bottles to identify the experiment.**

**Hold the dropper perpendicular to the substance you are dropping the liquid into.**

**Measure liquid amounts accurately by looking from the side of the beaker.**

**Measure dry substances by leveling across the top of the measuring spoon. Use a lab implement or the side of the baking soda box to level.**


### EDUCATOR NOTE

Remind students to wipe down the teaspoon if the same teaspoon is being used for different ingredients.

Keep the lava lamps for the following activity. Let them sit and separate into layers for Meeting 3.

## LAB: MAKE A GREENER LAVA LAMP

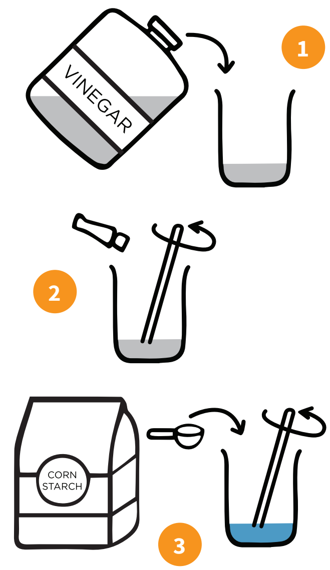
Students can follow steps 1 – 12 in their Student Guides to make a greener lava lamp.

**Beaker #1: 250 mL**

1. Measure 100 **mL** of vinegar in the 250-**mL** beaker over the aluminum tray.

2. Add 10 drops of natural blue food coloring, then stir with the stirring rod.

3. Slowly add ½ teaspoon of guar gum and stir. Let this sit for 2–5 minutes.

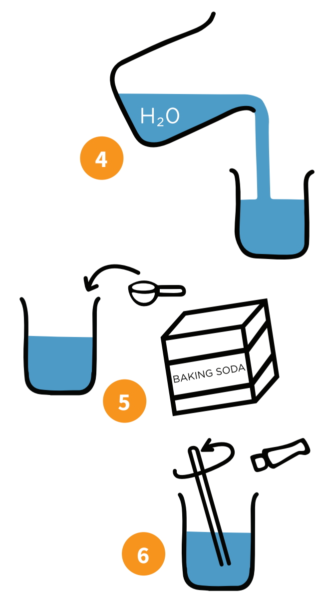



**Beaker #2: 250 mL**

4. Measure 100 **mL** of lukewarm tap water in the other 250-**mL** beaker.

5. Add 1 teaspoon of baking soda to the water.

6. Pick another color of natural food coloring and add 5 drops to the water and baking soda, then stir.



**Glass Bottle: 400 mL**

7. Use the wax pencil to label the 400-**mL** (12 oz.) glass bottle with “Lab Only” so it is clear that the bottle is no longer to be used for drinking purposes.

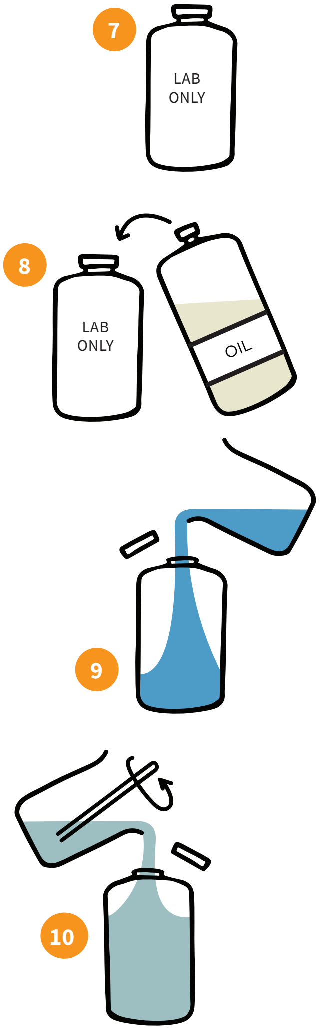
8. Fill the 400-**mL** (12 oz.) glass bottle halfway with vegetable oil. Let it sit for 2-5 minutes.

9. Slowly pour 100 **mL** from Beaker #1 (blue vinegar and guar gum solution) into the bottle containing the oil.

10. While stirring the contents of Beaker #2 (baking soda and water solution), slowly pour 10 to 20 **mL** at a time from Beaker #2 into the bottle to keep the lava from overflowing. You will want to add a total of 75 **mL** from Beaker #2 into the bottle.

11. Observe!

12. Leave the bottle on the tray. Your educator will cap it and store for the next meeting.




## POST-LAB CLEANUP

- All materials are safe to pour down the drain.
- Wipe any oil residue with a paper towel before washing the labware.
- Clean beakers, teaspoons, and stirring rods in a warm, soapy water bath with 30 **mL** of vinegar added.
- Instruct students to dry the tools and lab equipment, then store them properly.

## EDUCATOR NOTE

Talk through the mechanisms of the lava lamp with your class. The starting materials, which are all **benign**, are able to create two distinctive layers, making a **heterogeneous mixture**. The colored layer rises and falls due to having a different **density**, and the baking soda releases $CO_2$ to lift the layer. The bottom layer is more **viscous** and therefore moves like lava.

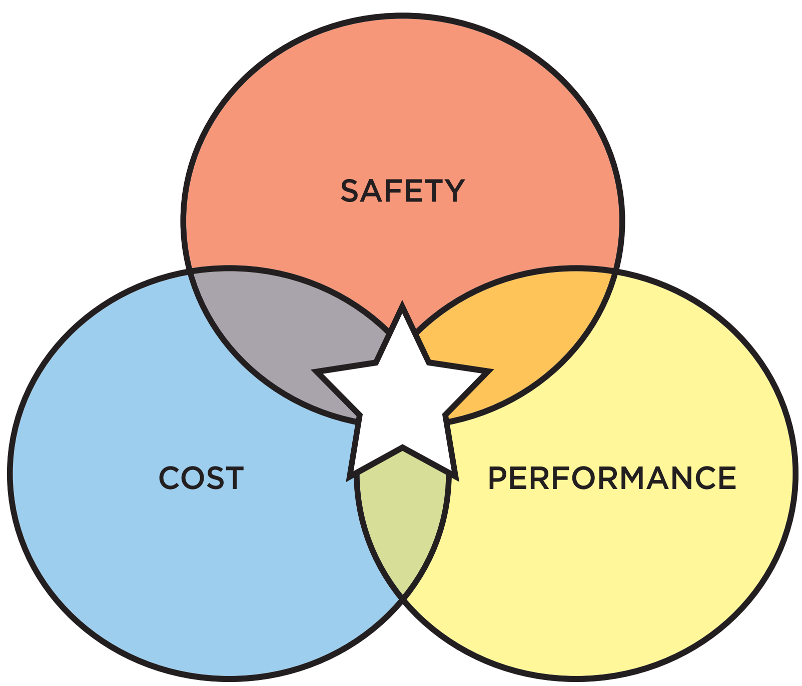
Ask students to explain **heterogenous** and **homogenous** layers in regard to their lava lamps. Ask students to explain why we would call our lava lamps **benign**.

## REFLECTION: GREEN CHEMISTRY INVENTION

Congratulations! Your students have just created a safer, cheaper, and equally effective lava lamp! Unfortunately, traditional lava lamps aren't the only invention with a **design flaw.** Many products have the **design flaw** of being harmful for us and the environment. That's why we need more inventors using **green chemistry** to create sustainable solutions.

As your students have learned, **green chemistry** is the field of study that specializes in making products while considering sustainability. **Green chemists** work with today's technologies and scientific procedures to invent products—inventions—that are useful and unique. These are judged based on three criteria: 1) safety, 2) cost, and 3) performance. The invention must be able to be produced at a low cost to be successful in the marketplace. The invention must also be safe for the people creating it, the people using it, and the environment where it is being produced and being used. In addition, for a **green chemistry** invention to be viable, it must perform well.

Amazingly, chemistry is involved in pretty much everything—from eating food to the shampoo you use. How your clothes were made, the formulation of the toothpaste you used, and how you got to school today all involved chemistry. Now, wouldn't it be great if we were able to do all of those things in a more sustainable way? That's what we're going to be working on in our upcoming activities: how to create more sustainable inventions using **green chemistry.**



## JOURNAL LOG

Journal logs provide a space to reflect and write observations. Content, original thoughts, and creativity are valued over organization. A journal log page is provided at the end of each meeting guide.

Suggestions for general note-taking:

- Indent when introducing a new idea,
- Make use of both numbered and alphabetical lists, and
- Title the page.

Reflective note-taking is important, too. Your students should:

- Write notes for a set amount of time (5 minutes at the end of every meeting).
- Feel free to write their own thoughts. Their notes will not be shared with the class.
- Take notes in both words and drawings.

Technical and scientific note-taking include both general and reflective note-taking. Have students practice what green inventors would do:

- Write summaries of their work each day,
- Sign their notebook or log at the end of each day,
- Date each entry,
- Write both quantitative and qualitative observations,
- Avoid using personal pronouns,
- Cite who they worked with, and
- Use key terms and other vocabulary introduced each day.

## SELF-ASSESSMENTS

Have students turn in their completed self-assessment as an exit slip when they leave.

## INDICATORS OF A SUCCESSFUL MEETING

Students are able to define **green chemistry.** They understand the importance of laboratory safety. They also consider how to make products friendlier or greener for the environment and can explain the three criteria of **green chemistry.** Additionally, students write summaries of their work in a daily log.

### EDUCATOR NOTE

Ask students to answer Extend The Learning questions in their journal logs.

### EXTEND THE LEARNING

**1. What chemical reactions caused the lava lamp to act the way it did?** *The baking soda releases $CO_2$ when it interacts with the vinegar.*

**2. Did you create a homogenous or heterogenous mixture?** *The starting materials, which are all benign, are able to create two distinctive layers, making a heterogeneous mixture.*

**3. What caused the movement that took place in the lava lamps?** *The colored layer rises and falls due to having a different density, and the baking soda releases $CO_2$ to lift the layer.*

**4. What layer is more viscous?** *The bottom layer is more viscous and, therefore, moves like lava.*

# JOURNAL LOG

## KEY TERMS

**Dilute (v):** to add solvent (such as water) to a solution without the addition of more solute, thereby decreasing the solution's concentration.

**Environment (n):** the surroundings or conditions in which a reaction takes place.

**Evaporation (n):** the action of turning a liquid into vapor.

**Extraction (n):** the action of taking something out.

**Filtration (n):** the action of filtering or removing something in a solution.

**Mold (v):** to form a shaped object out of an easily manipulated material like a plastic.


## TOOLS AND LAB EQUIPMENT

- 250-mL glass beakers, 4 per student group
- Aluminum tray, 1 per student group
- Hot plate, 1 per student group
- Heat-resistant gloves, 1 pair per student group
- Squeeze bottle, 1 per student group
- Stirring rod, 1 per student group
- Lab-made lava lamps, distributed to their respective groups
- 150-mL funnel

## MATERIALS AND LAB SUPPLIES

- Filter paper, 2 pieces per student group
- Wax pencil, 1 per student group
- Paper clips/wire hooks, 3 per student group
- Protective gloves, 1 pair per student
- Protective goggles, 1 pair per student
- Student Guides
- Alcohol

# MEETING 3

## PROCEDURE

This meeting will cover:

- Pre-Lab: Reacting to Reactions
- Lab Preparations
- Lab A: Dissect and Identify
- Lab B: Experiment and Test with Undiluted and **Diluted** Solutions
- Post-Lab Cleanup
- Reflection: Who Knew?
- Journal Log
- Self-Assessments
- Indicators of a Successful Meeting

## PRE-LAB: REACTING TO REACTIONS

Our everyday lives consist of many different reactions. We react to hearing a friend's story or smelling freshly baked cookies. We constantly react to what is going on in our lives and our **environment.** We are often the **reactant** and we undergo a reaction based on what is added to our situation**.** This causes a product, or an outcome, which is what we do next. The same components (**reactants** and **reagents**) are present in chemical reactions.

$$\text{Reactant} + \text{Reagent} \xrightarrow{\text{Reaction}} \text{Product}$$

**Reagents** react with **reactants** to create a new product. For example, imagine you are the **reactant** and you smell freshly baked cookies. Your **reagent** is the smell of cookies. You may undergo the reaction of suddenly feeling hungry for cookies! The product is your hunger. Have your students write the chemical reaction of the cookie example.

$$\text{You} + \text{Smell of cookies} \xrightarrow{\text{Reaction}} \text{Hunger}$$

**Plastic (n):** a synthetic material made from polymers.

**Plasticizer (n):** a substance added to a synthetic resin to promote plasticity and flexibility.

**Polymer (n):** a material that has a molecular structure consisting of large numbers of similar units bonded together.

**Reactant (n):** a substance that takes part in and undergoes change during a chemical reaction.

**Reagent (n):** a substance or mixture used in chemical reactions.

**Synthetic (adj):** made by a chemical synthesis..

**EDUCATOR NOTE**

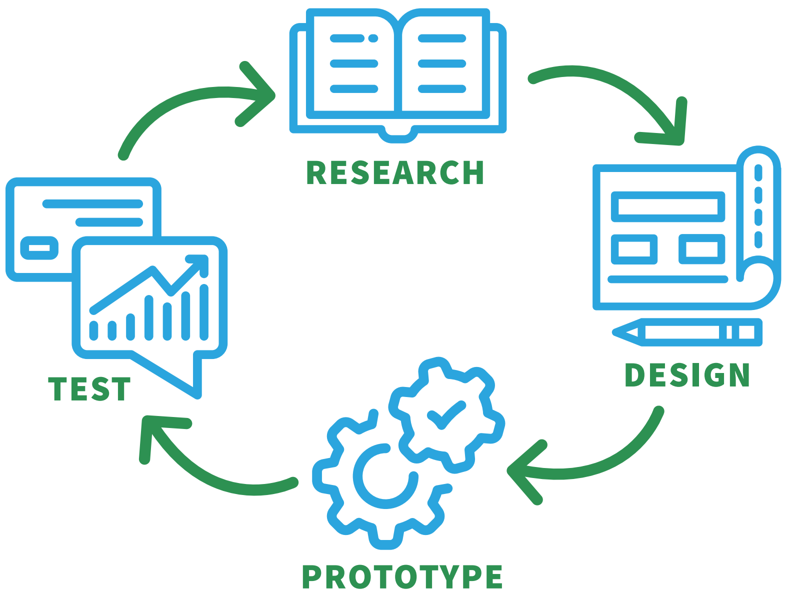
Set up three green chemistry work stations before the meeting begins:

1. **Evaporation**
2. **Filtration**
3. **Extraction**

Have each of the lab-made lava lamps set out on trays prior to students arriving.

In the last meeting, students were able to make a more sustainable lava lamp using the principles of green chemistry. The traditional lava lamp was made with materials unsafe to dispose of in a landfill. Currently, many products have the design flaw of not being sustainable. It is critical to consider the entire life cycle when designing green chemistry inventions.

**Invention Cycle**




*Lab-made lava lamp separated into its two layers after sitting out overnight.*

Our lava lamps were more cost effective, safer for the environment and people, and equally effective at creating a heterogenous mixture with two layers having differing viscosity. We caused a chemical reaction by mixing various substances that produced $CO_2$.

In this meeting, students are going to reexamine their lab-made lava lamp and explore how they can change the lava lamp's life cycle. When traditional inventions are done with their useful life, they tend to become waste, either going to landfills, or worse, becoming toxic waste. Since all of our materials are benign and we thought about sustainability at the inception of our lava lamps, we know they break down safely.

There is so much more to learn about what these **reagents** can do! Let's explore the **reagents** in different **environments** to see what reaction is caused. Students will dissect their lab-made lava lamp in Lab A to determine what the starting materials are in each solution. Afterward, in Lab B, students will test both **diluted** and undiluted solutions in three different **environments** (**filtration, evaporation,** and **extraction)**. Students will explore these components by treating them as **reagents** and testing them in the various **environments** to determine if a product can be formed.

**LAB ROLES**

**Have students decide the roles of each member of the group. Suggested roles are:**

**Formulator—responsible for chemicals**

**Talker—responsible for reading the procedure and communicating results**

**Doodler—responsible for recording observations**

**Organizer—responsible for setting up all non-chemical materials and for cleaning up glassware**

**Have students record their roles in their Student Guides. Remind them that they can take other roles in upcoming labs.**

## LAB PREPARATIONS

Before you begin, review the following safety rules as a class.

**SAFETY**

1. **Students and educators should wear gloves and goggles during labs from pre-lab setup to post-lab cleanup.**
2. **The bottles used with this lab are labeled "Lab Only." They should not be used for drinking purposes.**
3. **Be extra careful when using the hot plate.**
4. **Use heat-resistant gloves when handling the hot glassware.**
5. **Place warm glassware on the aluminum tray if the surface is not a lab bench.**
6. **Remember to turn off hot plates and all other heating devices after use.**
7. **Pour all components over a tray.**

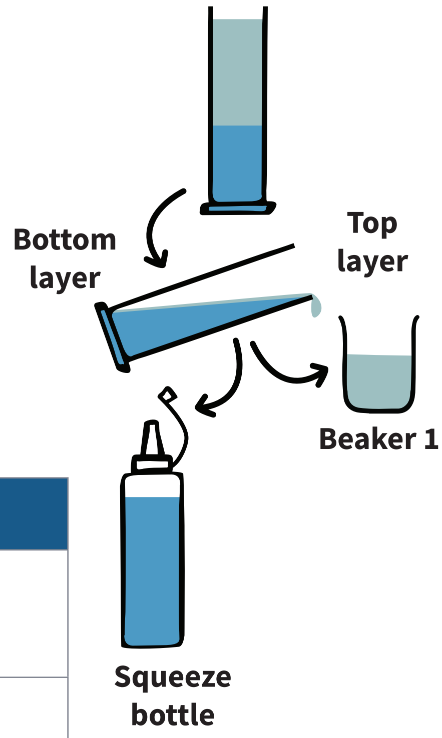
## REMINDERS

- Tell students to read through the lab before dissecting the lava lamp.
- Have students organize all of the materials they will use at their lab bench or station.
- The ingredients they used to make a lava lamp in Meeting 2 were: water, vinegar, food coloring, guar gum, baking soda, and oil.

## LAB A: DISSECT AND IDENTIFY

### Separation 1:

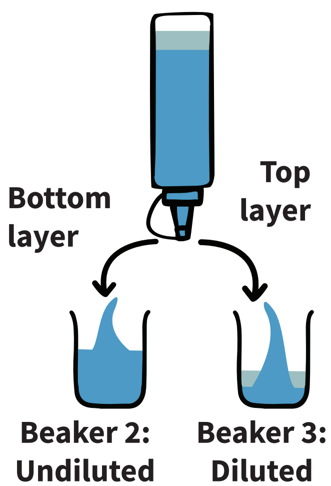
1. Pour the top layer of your settled lava lamp into Beaker 1. Remember to always pour over the tray.
2. Pour the bottom layer (remainder of the lava lamp) into the squeeze bottle and cap it.
3. Discard the contents of Beaker 1 as directed by your instructor. Then wash and dry it. You'll use it again in Lab B.




| Identify Components | |
|---|---|
| **Lava lamp** | Food coloring, vinegar, Guar Gum, Baking Soda, Water |
| **Beaker 1** | Oil |
| **Squeeze bottle** | Food coloring, vinegar, guar gum, baking soda, water (some oil) |

### Separation 2:

1. Flip the capped bottle upside down and let it settle into layers.
2. Label a second clean beaker "Undiluted" using the wax pencil.
3. Uncap the upside-down bottle over the "Undiluted" beaker and squeeze out the bottom layer.
4. Label a third clean beaker "Diluted" using the wax pencil.
5. Squeeze out the remainder of the fluid into the "Diluted" beaker.




| Identify Components | |
|---|---|
| **Beaker 2** | Food coloring, Vinegar, Guar Gum, Baking Soda, Water |
| **Beaker 3** | Food Coloring, Vinegar, Guar Gum, Baking Soda, Water (Some Oil) |

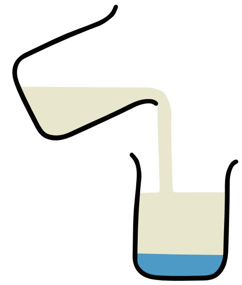
MEETING 3

### EDUCATOR NOTE

Imperfections in the separation of the two layers will not disrupt the reactions that subsequently occur.

6. Add 100 mL of tap water to the "Diluted" beaker to create a diluted solution.

| Identify Components | |
|---|---|
| **Beaker 3** | Food Coloring, Vinegar, Guar Gum, Baking Soda, Water (Some Oil) |

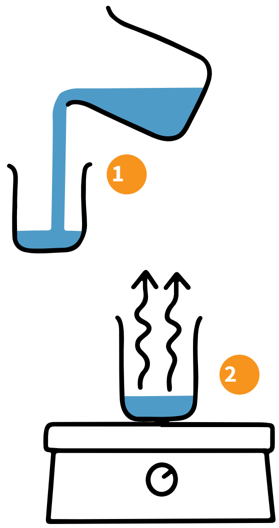


**Beaker 3: Diluted**


*Student completing Lab A, Activity Separation 2*

## LAB B: EXPERIMENT AND TEST WITH DILUTED AND UNDILUTED SOLUTIONS

### Evaporation




1. Label clean and dry beakers with “D” and “U” using the wax pencil.
2. Pour 30 mL from the “Diluted” and “Undiluted” beakers into their matching “D” and “U” beakers.
3. Turn on the hot plate and set to warm. Students should have an adult present while they learn how to operate a hot plate.
4. Hand the “D” and “U” beakers to your educator to place on the hot plate. It will take 6 to 8 minutes for the solution to solidify.
5. Turn off the hot plate after the solution solidifies.
6. Wearing heat-resistant gloves, carefully move the “U” and “D” beakers from the hot plate to the lab bench to cool.
7. Observe and record your observations.
8. Let the beakers cool. Then empty, clean, and dry them for the filtration experiment.

| | Diluted Solution | Undiluted Solution |
|---|---|---|
| **Observation** | Forms a thin plastic | Could form a thin plastic, but not as well |
| **Could this be useful?** | Similar to a candy wrapper | Similar to a candy wrapper |

### EDUCATOR NOTE

**Filtration** will not give substantial results, and may only form a globular structure when left to dry for a long time. Remind students that inconclusive results are just as important as conclusive results. Have the doodler write down the team’s observations.

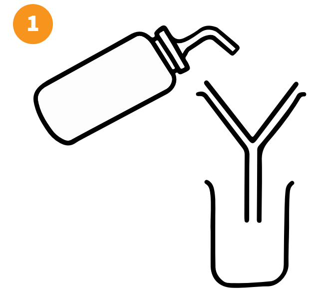
### EDUCATOR NOTE

Experiment with the heat settings on the hot plates. Some hot plates have number settings while others have low to high settings. Determine the appropriate setting for your hot plate prior to students completing this lab.

### SAFETY

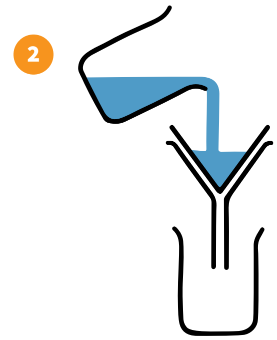
1. **Use extra care when using the hot plate.**
2. **Remember to turn off hot plates and all other heating devices after use!**

## Filtration




1. Fold the filter papers to fit the funnels. Wet the filter papers with water. Let excess water drain out.

2. Set the funnels over the two clean beakers ("D" and "U"). Pour 30 mL of each solution into the funnel over the matching beaker.




3. Observe and record observations.

4. Empty, clean, and dry the beakers for the Extraction experiment.

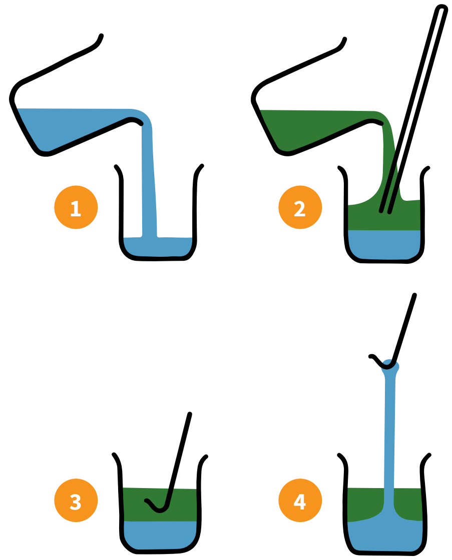
### EDUCATOR NOTE

A thin film should form in the dilute solution. A thicker, "clumpy" film should form in the undiluted solution.

| | Diluted Solution | Undiluted Solution |
|---|---|---|
| **Observation** | Difficult to filter, forms solid near top | Filters and creates nothing of interest |
| **Could this be useful?** | Putty or clay like if it dries out over time | No |

*Fitting the filter paper requires students to fold the filter paper in half and then in half again. They will then cut it to fit into the funnel. Next, have them wet the filter paper with water so it adheres to the sides of the funnel.*

## Extraction



1. Pour 15 mL of each solution into the matching beakers.
2. Add 15 mL of alcohol to the top of each of the beakers. Pour onto the stirring rod to keep the alcohol from breaking the surface of the solution.
3. Use a wire hook or unfolded paper clip to pass through the top layer of solution "U" and dip into the top of the bottom layer. Hook the surface of the bottom layer and pull upward.
4. Observe and record observations.
5. Repeat with solution "D."

| | Diluted Solution | Undiluted Solution |
|---|---|---|
| **Observation** | Filters and creates nothing of interest | Difficult to filter, forms solid near top |
| **Could this be useful?** | No | Putty or clay like if dries out over time |

### EDUCATOR NOTE

The **extraction** should produce a thin string when pulling through the surface of the undiluted solution. The **diluted** solution should not be able to produce any substance when pulling the wire through its surface.

**HISTORY**

Nylon was invented using an extraction technique. Wallace Hume Carothers and a team of chemists with the du Pont Company invented the synthetic material in 1939. The team had been working on polymers. Nylon was marketed to the public in 1940 as hosiery for women. Nylon replaced the high-priced silk and hosiery became known as "Nylons." Soon thereafter, du Pont produced nylon for many markets during World War II, including parachutes and mosquito nets. Today, nylon is used in a multitude of products including toys, fishing line, and medical devices.

*Hagley ID, Box/folder number, E.I. du Pont de Nemours & Company Advertising Department records (Accession 1803), Manuscripts and Archives Department, Hagley Museum and Library, Wilmington, DE 19807*

*Access to this item is provided for educational and research purposes only.*

## POST-LAB CLEANUP

- All materials are safe to pour down the drain.
- Have students wipe any oil residue with a paper towel before washing the labware.
- Ask students to clean beakers, teaspoons, and stirring rods in a warm, soapy water bath with 30 mL of vinegar.
- Instruct students to dry the tools and lab equipment, then store them properly in an area you designate.

### EXTEND THE LEARNING

**Alcohols often have -ol at the end of their names. In this lab we used Ethanol; in the next meeting we will use Sorbitol. Other alcohols that are also plasticizers include glycerol and mannitol.**

**1. What differences did you observe between the diluted and undiluted solutions?**

*The diluted solution contains more water and therefore created a thinner sheet during heating. The diluted solution is unable to create a thread during the alcohol extraction.*

**2. What conclusions can you draw about the amount of water in the solutions and the properties of the plastic?**

*The more water, the more flexible and malleable the plastic is. However, it may also require more time heating to form into a plastic.*

**3. How does the rate of heating or evaporating in our samples impact the properties of the plastic?**

*The evaporating samples are less likely to crack after checking back on them the next day.*

## REFLECTION: WHO KNEW?

Our first reaction may be that nothing useful was produced. Remember, when we invent, we must look at what we perceive as failed trials and explore the results. Could we have accidentally made something without being able to recognize it? What you probably didn't know is that a chemical reaction happens when a **starch,** like guar gum, is heated in the presence of an acid, like acetic acid in vinegar. The chemical reaction produces a **plastic.** It would be hard to recognize this if you've never studied **plastics. Plastics** are defined by their properties, not by their materials. To be a **plastic,** a material must be able to **mold** into shape when soft and then set into a rigid or slightly elastic form.

Additionally, the alcohol layering on the undiluted solution should have produced a thin string. This, in fact, is how nylon is made. The alcohol dehydrates the solution to create a **plastic** with different properties. In fact, **plasticizers,** or materials that promote plasticity and flexibility, are often alcohols.

In our next meeting, we'll explore the many roles of **plastics** in our lives and see if we can make a replacement **plastic.** Traditional **plastics** may take 1,000 years to degrade, while one made of these natural sources would be able to break down in weeks. Let's try to make a greener **plastic** based on safety, cost, and performance.

## SELF-ASSESSMENTS

Collect the completed self-assessments as exit slips when students leave.

## INDICATORS OF A SUCCESSFUL MEETING

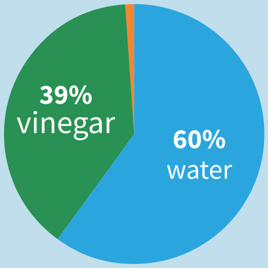
Students can **evaporate, filter,** and **extract** materials from solutions. Students can form a **bioplastic** and understand the importance of the source of materials in a product's life cycle.

MEETING 3

### EDUCATOR NOTE

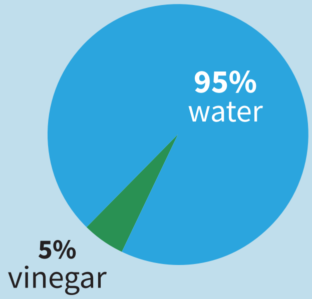
You may choose to engage in a conversation with your students about ratios within solutions. You can discuss with them that the amount of water within the solution increased by a large percentage when diluted. Pie charts help to describe this, as well as how the amount of water added fundamentally changed the solution that was made.

**Undiluted**




**Less than 1%:**
Coloring, Baking Soda, Starch

**Diluted**




**Less than 1%:**
Coloring, Baking Soda, Starch

# JOURNAL LOG

# JOURNAL LOG

# SUSTAINABLE PLASTICS EDUCATOR GUIDE

## MEETING 4: EXPERIMENTING WITH BIOPLASTICS

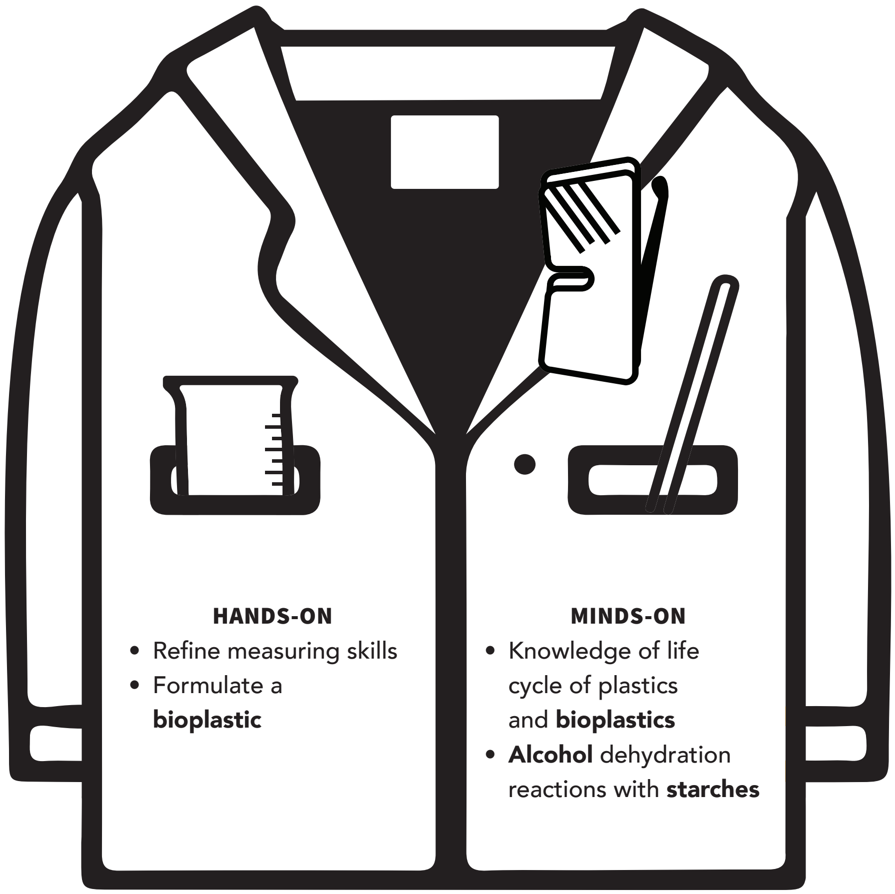
### KEY TERMS

**Acid (n):** a molecule that can donate a proton or accept an electron pair in reactions.

**Alcohol (n):** any organic compound whose molecule contains one or more hydroxyl groups attached to a carbon atom.

**Bioplastic (n):** a biodegradable plastic made from biological substances instead of petroleum.

**Biological material (n):** matter that has come from a once-living organism.




### TOOLS AND LAB EQUIPMENT

- 250-mL beakers, 3 per student group
- Aluminum tray, 1 per student group
- Heat-resistant gloves, 1 pair per student group
- Hot plate, 1 per student group
- Stirring rod, 1 per student group
- Syringes, 1 per student group
- Teaspoon (tsp.) measure, 1 per student group

### MATERIALS AND LAB SUPPLIES

- Wax pencil, 1 per student group
- Timer, 1 per student group
- Protective gloves, 1 pair per student
- Protective goggles, 1 per student
- Photocopies of Tracing Loops sheet, 1 per student
- Tapioca **starch**
- White vinegar
- Sorbitol
- Wax paper
- Tape
- Student Guides

MEETING 4

## PROCEDURE

This meeting will cover:

- Plastics in our World
- Pre-Lab: What's a **Bioplastic?**
- Lab Preparation
- Lab: Experimenting with **Bioplastics**
- Post-Lab Cleanup
- Reflection: **Bioplastic** Properties
- Journal Log
- Self-Assessments
- Indicators of a Successful Meeting

## PLASTICS IN OUR WORLD

Have students take a plastics inventory in the classroom or lab. Ask them to look on desks and lab benches, at the AV equipment, and even in their backpacks. What about their clothing—do they see any plastics?

1. Ask students to write down as many plastic objects as they can in their Student Guide within five minutes.
2. Ask them to share observations within their groups.
3. How many different items did each group see?
4. Ask students to reflect on why plastics were used in these products.

Chances are that most of the plastics students have identified are petroleum-based. Read about the life cycle of these plastics and highlight all the stages of the life cycle that could be improved upon to make the process more sustainable for the health of humans and the environment.

**Crude oil (n):** unrefined petroleum.

**Replicate (v):** to copy or repeat something.

**Starch (n):** an odorless, tasteless white substance naturally occurring in plant tissue; it stores carbohydrates.

**Wastewater (n):** water that is not clean because it has already been used in homes, businesses, factories, etc.

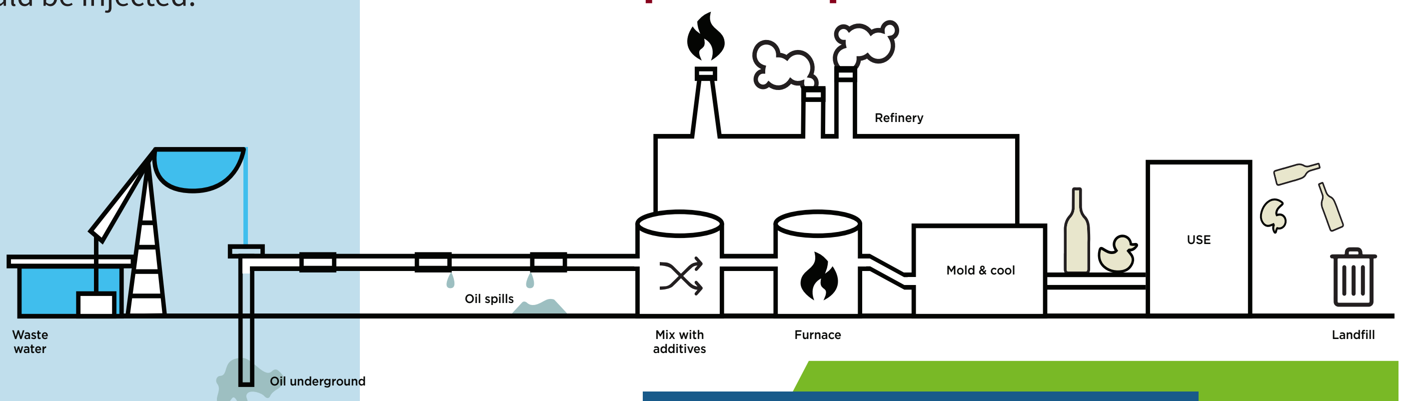
Petroleum-based plastic is made from **crude oil,** a nonrenewable resource. **Crude oil** is obtained by drilling into vast underground reservoirs. To extract the **crude oil,** a large amount of clean water is used, generating unusable **wastewater.** A large infrastructure is built to get the oil to ground level. Once there, the oil is pumped through a pipeline; these pipelines are sometimes thousands of miles long. The production and transportation of oil through these pipelines have two major risks—pipeline leaks and oil spills—which cause immediate and long-term environmental damage. The **crude oil** then goes to a refinery to be processed into different types of fuel and chemicals. The oil for plastic gets processed into small pellets. Additives are mixed in, more water is used, and strong **acids** are added to break down the pellets; these processes all contribute to additional risks in the production of plastic. Finally, the pellets are heated at extremely high temperatures in a furnace. Once melted, the material is poured into a mold and left to harden into its final plastic form. While many petroleum-based plastics are recyclable, a vast majority of them end up in landfills. These plastics last in the environment for approximately 400 years, on average. An overwhelming 93% of all plastics consumed in the United States are not recycled.

## EDUCATOR NOTE

While students are getting settled, play **Drowning in Plastic** to give a scale of how many plastics are used in a minute.

Examples of plastics formed in different ways include plastic bags, which would be blown, and water bottles, which would be injected.

## The lifeline of petroleum plastic




### EXTEND THE LEARNING

The field of **bioplastics** is vast and many scientists are inventing alternatives to petroleum-based plastics. Scientists are looking at how bees make honey in order to invent waterproof jackets, and Apple® is using **bioplastic** for the cover glass frames in their iPhone Xs. Many new companies are discovering breakthrough ideas by inventing with **bioplastics**. Loliware™ is one of these companies. They have invented a straw made of only **bioplastic.**

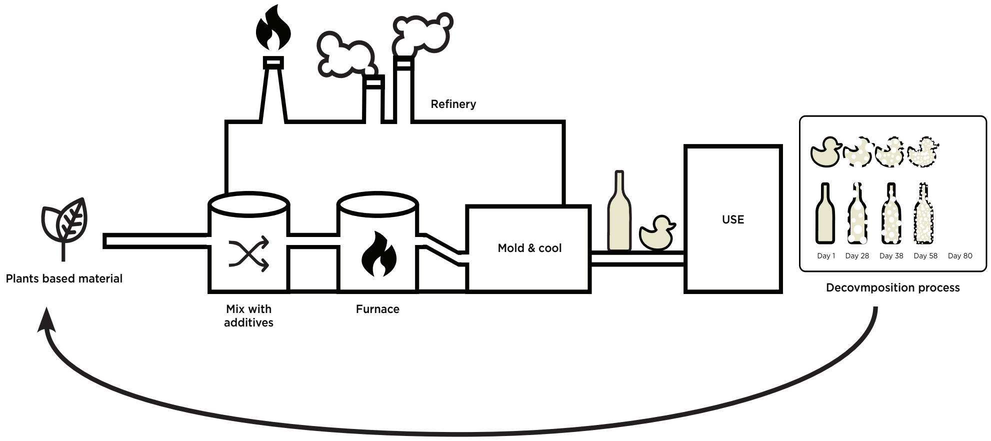
## Pre-Lab: What's a Bioplastic?

Looking at the life cycle, students can see that petroleum oil is extracted from the ground and they may think to themselves, "If it comes from nature, shouldn't that make it sustainable?"

Petroleum oil comes from deep in the ground and takes tens of millions of years to create, but humans consume oil at a much faster rate than it is made. The process of extracting oil from the ground also involves generating a lot of **wastewater,** and digging into the earth to extract the petroleum oil can disrupt the natural ecosystems.

**Biological material**, or living materials, can be grown and harvested above ground. This makes **biological material** more accessible, and they have a smaller environmental impact. Many companies have used **biological material** sources to make plastics to be more cost effective and sustainable than traditional petroleum oil-based plastics.

## The life cycle of bioplastic



Depending on where you are in the world, different **starches** are used as the **biological material** in **bioplastics.** We previously used guar gum as our **starch** material. In this lab, we will use tapioca **starch** as our **starch** material, instead of guar gum. Tapioca starch is understudied in the **bioplastic** field, which gives students a lot of opportunities to discover novel formations for creating new products.

### EDUCATOR NOTE

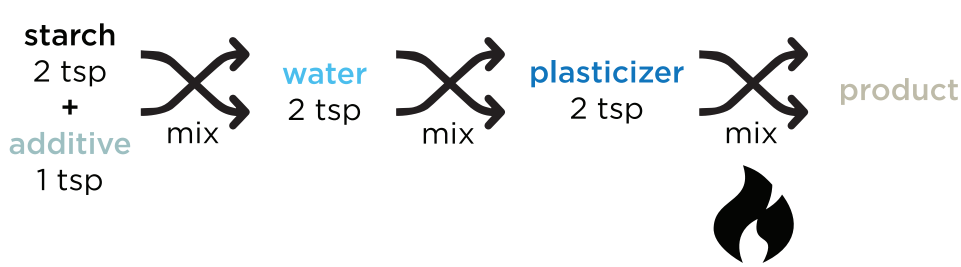
If you want to expand upon science literacy and communication, share this student-friendly reading: **How to Make Sneakers Out of Trash**

**EXTEND THE LEARNING**

Scientists tend to use the **bio** source that is most abundant in their geographical region. Why would this matter when thinking about practicing green chemistry? These scientists are able to use machinery to change the **bio** source into whatever size they desire. What region would be using what type of starch?


We will now create **bioplastics** with our **starch, alcohol,** and additive. These are the three components to making a **bioplastic.** To optimize our **bioplastic**-making process, we will create six uniform loops using our syringe and a formulation with tapioca **starch,** white vinegar, and sorbitol.

## Making Bioplastics



MEETING 4

LAB ROLES

As a group, decide who will be in each role today. Remember that you can take other roles in upcoming labs. Suggested roles and responsibilities are:

**Formulator**—responsible for chemicals

**Talker**—responsible for reading the procedure and communicating results

**Doodler**—responsible for recording observations

**Organizer**—responsible for setting up all non-chemical materials and for cleaning up glassware

## EDUCATOR NOTE

Remind students that the person handling the beaker must wear heat-resistant gloves.

Students will stir the solution as it heats on the hot plate until the solution starts to thicken. Students will keep stirring until the solution has a gel-like consistency. Heating the solution for too long can cause the plastic to become rigid or burn.

## LAB PREPARATIONS

Before you begin, review the following safety rules as a class.

## REMINDERS

- Tell students to read through the lab before beginning.
- Have students organize all of the materials they will use at their lab bench or station.

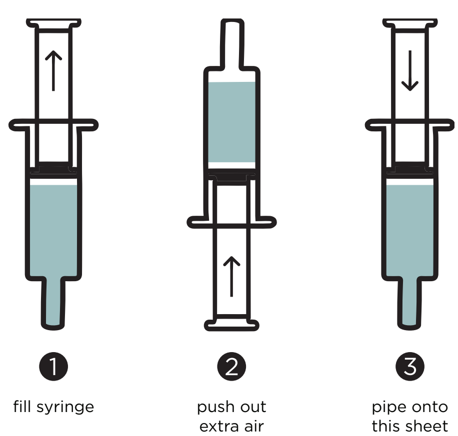
SAFETY

1. **Students and educators should wear gloves and goggles during labs from pre-lab setup to post-lab cleanup.**
2. **The bottles used with this lab are labeled "Lab Only." They should not be used for drinking purposes.**
3. **Be extra careful when using the hot plate.**
4. **Use heat-resistant gloves when handling the hot glassware.**
5. **Place warm glassware on the aluminum tray if the surface is not a lab bench.**
6. **Remember to turn off hot plates and all other heating devices after use.**
7. **Pour all components over a tray.**

## LAB: EXPERIMENTING WITH BIOPLASTICS

Tell students to follow these steps in their Student Guides:

1. Place wax paper over your Tracing Loops sheet and tape it to the tabletop.
2. In a 250-mL beaker, use a teaspoon to measure 2 tsp. of tapioca **starch** and 1 tsp. of white vinegar. Mix with the stirring rod.
3. Measure 2 tsp. of water and add to your beaker. Mix with the stirring rod.
4. Measure 2 tsp. of sorbitol and add to your beaker. Mix with the stirring rod.
5. Stir the solution until uniform.
6. Turn on the hot plate and set to medium. Using a timer, heat the solution for 6–10 minutes, stirring for 15 seconds every minute until the solution starts to thicken.
7. When the solution reaches a gel-like consistency, turn off the hot plate and remove the beaker from the heat.
8. Using your stirring rod, transfer the material from the beaker into the syringe.
9. Push the material as close to the end as you can.
10. Insert the plunger and flip the syringe upward.
11. Push out excess air.
12. Trace the loops on the tracing sheet using your syringe.
13. Steps 2–12 can be repeated twice more, if time allows.
14. Let your **bioplastic** material sit overnight to form.



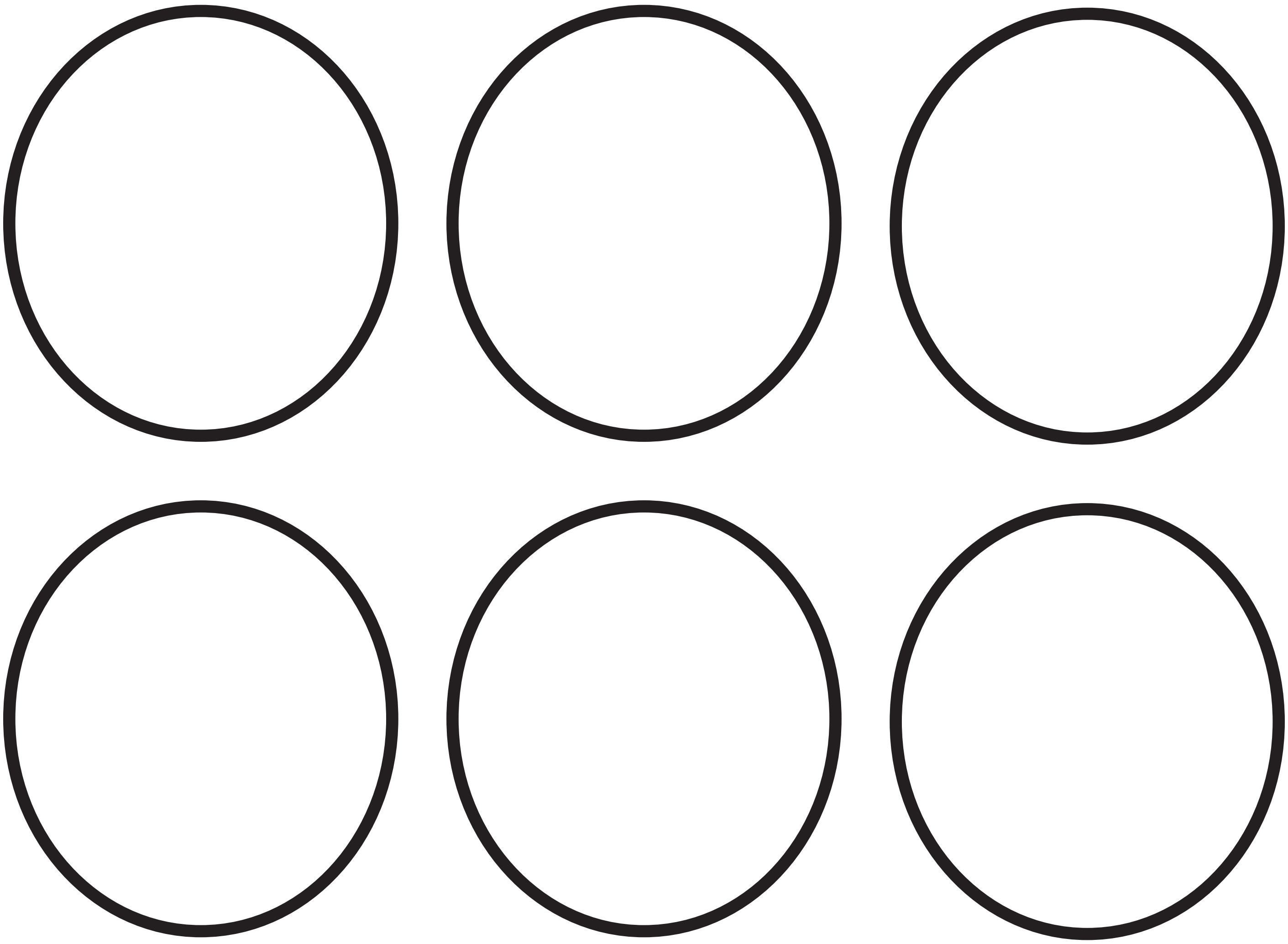

### EDUCATOR NOTE

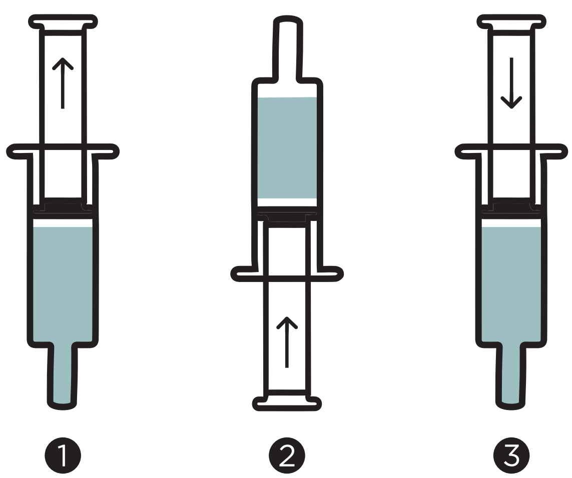
There are many types of bioplastics that the students may make. They may select what plasticizer, starch, and additive they want to use. There are amounts they should be using consistently for each category. However, with this variation, there is a wide range of time each solution takes to heat. The average range is 3-10 minutes, which is mostly dependent on the starch selected. Encourage students to make connections between outcomes and materials selected.

*Students measuring tapioca starch to create their bioplastic material.*

*A student modeling how to use a syringe to complete the Tracing Loops sheet.*

# TRACING LOOPS





*Students heating their solution while stirring for 15 seconds every minute.*

## POST-LAB CLEANUP

- All materials are safe to pour down the drain.
- Have students wipe any residue with a paper towel before washing the labware.
- Ask students to clean beakers, teaspoons, and stirring rods in a warm, soapy water bath with 30 mL of vinegar.
- Instruct students to dry the tools and lab equipment, then store them properly in an area you designate.

## REFLECTION: BIOPLASTIC PROPERTIES

Why did we make six identical loops? Scientists often make many samples, or **replicates,** of trials to find the best way to do something. This allows them to do material testing, or compare the properties of the samples, afterwards. In their groups, have students identify what properties would be ideal for their **bioplastic.** Ask them to think about possible products they could make with these properties.

| Structure: | Transparency: | Texture: |
|---|---|---|
| • Stiff<br>• Flexible<br>• Breakable<br>• Bendable<br>• Rubber-like<br>• Moldable | • Clear<br>• Opaque<br>• Holds Strong Color<br>• Tinted Color | • Slimy<br>• Sticky<br>• Chalky<br>• Smooth<br>• Tacky |



### EDUCATOR NOTE

If you would like structured learning, identify the properties you will look for as a class. A recommended product is window clings. Students can make variations in their products with varied cookie cutters but work with the same formulation. The formulation for window clings is white vinegar, tapioca, and sorbitol. They would be working toward properties such as flexible, tinted color, and sticky.

## SELF-ASSESSMENTS

Collect the completed self-assessments as exit slips when students leave.

## INDICATORS OF A SUCCESSFUL MEETING

Students are able to set up multiple experiments to make a **bioplastic.** Students can identify why **bioplastics** are more sustainable than petroleum-based plastics. Students understand why there is a need to invent new sustainable solutions. Experiments, formulas, and observed results are accurately described in their Logs and can be used to make optimization decisions.

### EDUCATOR NOTE

Students should be able to make 2–3 loops per formulation.

### EXTEND THE LEARNING

**Think back to the plastics identified in the beginning of the meeting.**

**1. Could any of these be replaced with bioplastics? Plastic food wrap for covering food could be replaced with bioplastics.**

*How long should we plan for these products to remain in use? Plastic food wrap is usually a single use item, so we could plan for it to remain in use for one month.*

**2. Similarly, how long should we plan for them to last until they biodegrade?**

*If we plan for the plastic food wrap to remain in use for one month, we would want it to biodegrade soon thereafter. We can plan for the plastic food wrap to biodegrade within a year.*

**3. Compare the stages of the life cycle of bioplastics with the life line of traditional plastics. Notice that one is a cycle, while the other is in a line. What does this tell you about their life cycles?**

*Use the key terms to help cover key components. Common plastics, such as fossil-fuel plastics, are derived from petroleum. Petroleum is not a renewable resource since it takes millions of years for oil to replenish itself underground. Bioplastics are plastic materials produced from renewable biomass sources and are able to biodegrade.*

# JOURNAL LOG

## KEY TERMS

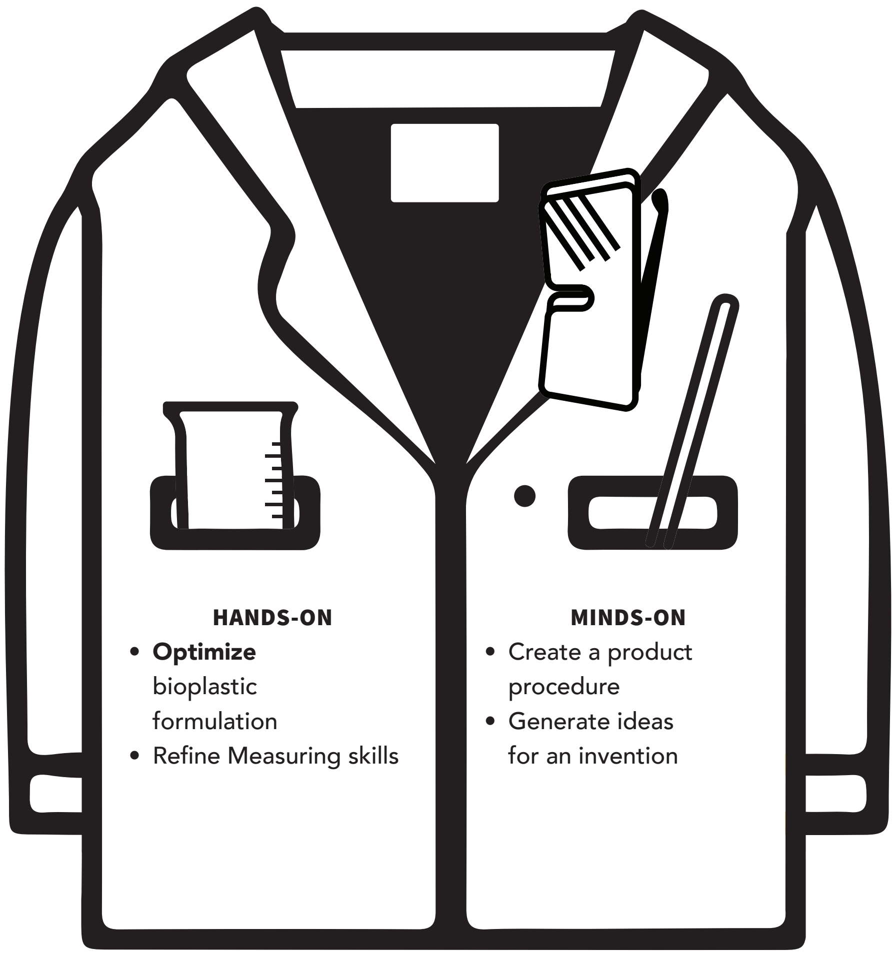
**Acidity (n):** the amount of acid in a substance.

**Cross-link (n):** A chemical bond of one polymer chain to another.

**Molecule (n):** a group of atoms that are bonded together and make up the smallest unit of a chemical compound.

**Monomer (n):** a molecule that can be bonded to other like molecules to form a long-chain polymer.

**Optimize (v):** to make a material as effective or functional as possible.




## TOOLS AND LAB EQUIPMENT

- 250-mL beakers, 3 per student group
- Aluminum tray, 1 per student group
- Heat-resistant gloves, 1 pair per student group
- Hot plate, 1 per student group
- Stirring rod, 1 per student group
- Syringes, 1 per student group
- Teaspoon (tsp.) measure, 1 per student group

## MATERIALS AND LAB SUPPLIES

- Wax pencil, 1 per student group
- Timer, 1 per student group
- Protective gloves, 1 pair per student
- Protective goggles, 1 per student
- Wax paper
- Tape
- Additives: white vinegar, baking soda
- Coconut oil
- Cookie cutter molds (various designs)
- Sorbitol
- Tapioca starch
- Tracing Loops Sheet
- Student Guides

## PROCEDURE

This meeting will cover:

- Pre-Lab: Method for **Optimizing**
- Safety
- Lab: **Optimize** Formulations
- Post-Lab Cleanup
- Reflection: What to make?
- Journal Log
- Self-Assessments
- Indicators of a Successful Meeting

# MEETING 5

**pH (n):** a scale that expresses acidity (lower numbers) or alkalinity (higher numbers) of a solution on a logarithmic scale of 1–14, on which 7 is neutral.

**Polymer (n):** a substance whose molecular structure is made up of large numbers of similar units (monomers) that are bonded together.

**Variable (n):** something that can change, especially in a way that cannot be known in advance.

## PRE-LAB: METHOD FOR OPTIMIZING

Look back at students' loops from the last meeting. Have students walk around to other groups' stations and compare how their loops are similar or different. Remind students to be careful when handling other groups' samples.

Have students answer the following questions and then discuss as a class.

1. Do any of the students' loops have the properties they wanted?

_______________________________________________________

2. Do the loops of other groups look the way students wanted? What qualities were they aiming to achieve and how did they achieve those qualities?

_______________________________________________________

These loops varied because of different executions of the same procedure. But what if we purposely introduced new **variables** to cause different properties in our samples?

The bioplastic properties are determined by two factors: 1) the concentration of the solution, and 2) the acidity or basicity of the solution.

## CONCENTRATION

The bioplastic properties are determined in part by how much water is in the solution. If more water is added into the solution, the solution becomes more dilute, or less concentrated. The less concentrated the solution, the more flexible the final product.

## ACIDS AND BASES

Plastics come in many shapes and forms, and their properties change based on the chemical reactions that occur when they are created. Our starting material, starch, is a polymer, or long chain, of sugars. The polymer chains of sugars interact with each other through bonding, or **cross-linking**. Lots of bonds between the chains create a rigid structure, while less bonds between the chains create a loose and flexible structure.

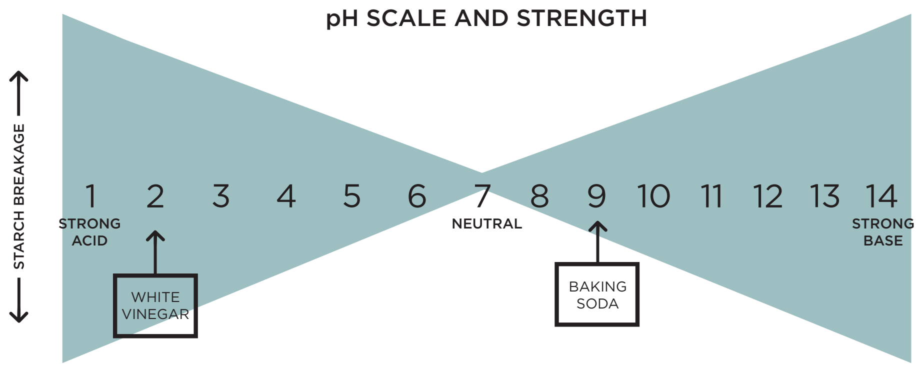
**pH**, or how acidic or basic an environment is, impacts how much bonding (**cross-linking**) occurs. A strong acid or base blocks some **cross-linking** when creating your bioplastic. Putting your starch polymer in a weak acid or base environment will keep more of the **cross-linking** bonds intact, and create a more rigid product.


### EDUCATOR NOTE

If your students want more information about **variables** within their bioplastic creations, refer them to the Reference sheet from Meeting 1. This will provide them with information on granule sizes of different starches and how that changes their material's surface area. The Reference sheet also provides information on the effect of **pH** on their solution. Additionally, if they choose, they can introduce other household additives to change the **pH**.

**pH** is an important factor when conducting chemical reactions. The **pH** of a solution is a measure of the acidity or basicity of the solution. Stronger acids or bases create smaller pieces, or smaller **polymers**. The plasticizer and heat rebind the smaller pieces into moldable, long-chain **polymers**.

One can tell how strong an acid or base is by how far it is from 7 on the **pH** scale. The scale ranges from 1 (strong acid) to 7 (neutral) to 14 (strong base). Today, you will choose the strength of the acid or base your group will use. This will change the properties of your products.




**EXTEND THE LEARNING**

**Have students predict what the strength of their acid will do to their product.**

*A stronger acid will break down bonding of the starch into smaller pieces. The more breaks in the bonding, the more flexible the bioplastic will become. Less cross-linking creates a more flexible bioplastic, while more cross-linking creates a more rigid bioplastic when they rebind with the plasticizer*

## EDUCATOR NOTE

**Acidity** tells us the concentration of hydrogen in a solution, or how many hydrogen ions there are to donate protons in a solution. The more hydrogen atoms to donate protons, the more acidic the solution is. **pH** tells us how acidic or basic a solution is depending on how willing it is to donate or receive protons.

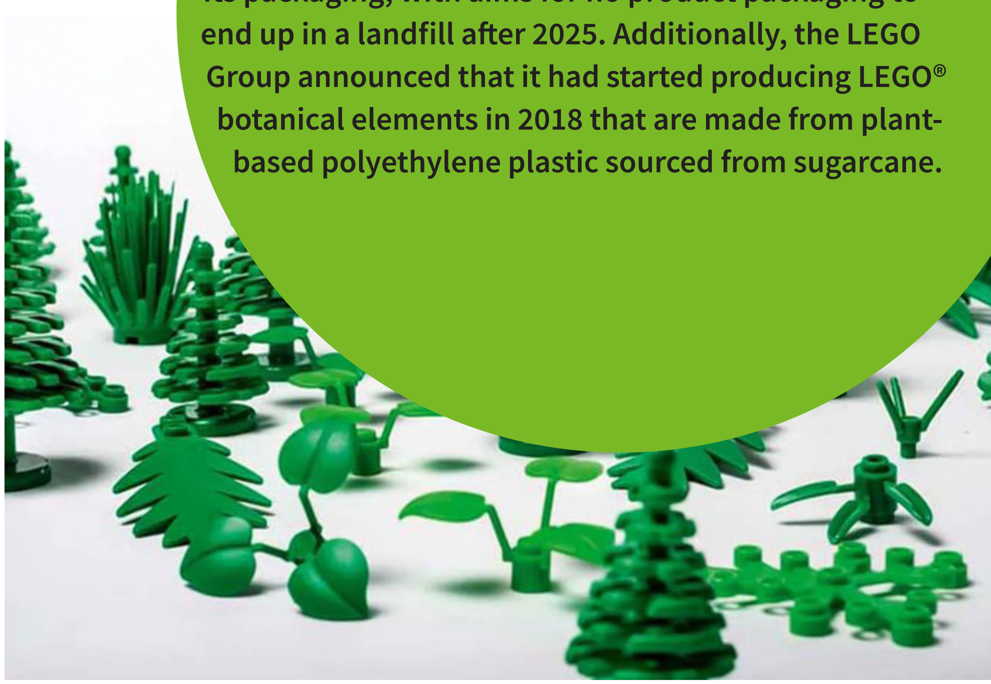
For more information on **pH**, watch **this Crash Course.**

Today, students will do a material test with their own bioplastic formulations. Students will later decide how to use their bioplastics in a new and innovative way. Have students consider whether their design would benefit from using loops or using cookie cutters. Discuss and write down the benefits of both and have students come to a decision as a group.

| Loops | Cookie Cutters |
|---|---|
| 1. | 1. |
| 2. | 2. |
| 3. | 3. |
| 4. | 4. |
| 5. | 5. |

**INVENTOR SPOTLIGHT**

In 2015, the LEGO Group announced that it would invest in research and development to search for sustainable materials as alternatives for current materials used in bricks and packaging. The company announced plans to hire employees specifically for a new Sustainable Materials Center. The company committed to first tackle its packaging, with aims for no product packaging to end up in a landfill after 2025. Additionally, the LEGO Group announced that it had started producing LEGO® botanical elements in 2018 that are made from plant-based polyethylene plastic sourced from sugarcane.



MEETING 5

## LAB PREPARATIONS

Remind students to put on protective gloves and goggles before starting the lab and to review the safety rules.

### LAB ROLES

Have students decide the roles of each member of the group. Suggested roles are:

**Formulator**—responsible for chemicals

**Talker**—responsible for reading the procedure and communicating results

**Doodler**—responsible for recording observations

**Organizer**—responsible for setting up all non-chemical materials and for cleaning up glassware

Have students record their roles in their Student Guides. Remind them that they can take other roles in upcoming labs.

### EDUCATOR NOTE

The person handling the beaker must wear heat-resistant gloves.

If time allows, students can add 2 tsp of whatever starch they have chosen to work with. This will introduce a new **variable** in their bioplastic formulation, in addition to changing **pH**.

## REMINDERS

- Tell students to read through the lab before beginning.
- Have students organize all of the materials they will use at their lab bench or station.

### SAFETY

1. Students and educators should wear gloves and goggles during labs from pre-lab setup to post-lab cleanup.
2. 2. The bottles used with this lab are labeled "Lab Only." They should not be used for drinking purposes.
3. Be extra careful when using the hot plate.
4. Use heat-resistant gloves when handling the hot glassware.
5. Place warm glassware on the aluminum tray if the surface is not a lab bench.
6. Remember to turn off hot plates and all other heating devices after use.
7. Pour all components over a tray.

## LAB: OPTIMIZE FORMULATION

Students can then follow these steps in their Student Guides to create a bioplastic product:

1. Tape wax paper onto the tabletop (over the Tracing Loops sheet, if using it). If using cookie cutters, cover them in coconut oil.
2. Use the wax pencil to label your beaker with the plasticizer, additive, and starch you will use.
3. In a 250-mL beaker, use a teaspoon to measure 2 tsp. of starch and 1 tsp. of your acid or base. Mix with the stirring rod.
4. Measure 2 tsp. of water and add to your beaker. Mix with the stirring rod.
5. Measure 2 tsp. of plasticizer and add to your beaker. Mix with the stirring rod.
6. Mix the solution until uniform.
7. Turn on the hot plate and set to medium. Using a timer, heat the solution for 6–10 minutes, stirring for 15 seconds every minute until the solution starts to thicken.
8. When the solution reaches a gel-like consistency, turn off the hot plate and remove the beaker from the heat.
9. Using your stirring rod, transfer the material from the beaker into the syringe.
10. Push the material as close to the end as possible.
11. Insert the plunger and flip the syringe upward.
12. Push out excess air.
13. Use the syringe to either fill a cookie cutter or make a loop.
14. Let your bioplastic material sit overnight to form.
15. Steps 2–14 can be repeated twice more with a clean beaker, if time allows.

# OPTIMIZE BIOPLASTICS

**Formulation**

starch 2 tsp + additive 1 tsp → mix → water 2 tsp → mix → plasticizer 2 tsp → mix → product

**Goals for Prototype:**

**Materials**

| Starch | Additive | Plasticizer |
|---|---|---|
| Tapioca | Baking Soda | Sorbitol |
| | White Vinegar | |
| | | |
| | | |

| Starch | Additive | Plasticizer | Product Properties |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

## POST-LAB CLEANUP

- All materials are safe to pour down the drain.
- Have students wipe any residue with a paper towel before washing the labware.
- Ask students to clean beakers, teaspoons, and stirring rods in a warm, soapy water bath with 30 mL of vinegar.
- Instruct students to dry the tools and lab equipment, then store them properly in an area you designate.

## REFLECTION: WHAT TO MAKE?

Ask students the following questions and give them time to record their answers in their Student Guides.

Is there one formulation that stands out from the others based on the group's **optimization** trials? How well did the formulation trials meet student's goals for their material?

It is now time for the students to start thinking about what they want to make with their **optimized** formulations! Whether it be a figurine, emblem, or stamp, the finished prototype is only limited by the materials present and by size. Size constraints include that it must be smaller than half of a sheet of paper in order to diagram the dimensions within the notebook.

Have students sketch their bioplastic prototype ideas in their journals. They can brainstorm what materials they need to create the mold that will form their bioplastic product. Have students refer to the Optimizing Bioplastic Procedure as they identify the materials needed to shape and mold their bioplastic prototype.

Encourage students to use the time between this meeting and the next one to brainstorm what they would like to make!

## SELF-ASSESSMENTS

Collect the completed self-assessments as exit slips when students leave.

## INDICATORS OF A SUCCESSFUL MEETING

Students can reflect on material properties and characteristics of the initial bioplastic trials. They can identify the materials needed to formulate an **optimized** bioplastic.

*Student stirring their solution.*

MEETING 5

**EXTEND THE LEARNING**

Even with this understanding of how different factors change bioplastic properties, it is difficult to predict results. This is because there are still other variables to consider:

- Water interacts with the starch molecules to determine the viscosity of the solution.
- The surface area of the starch granules contributes to how much the water is able to interact with the starch molecules. Water can interact more with starch that has smaller granules, thus dissolving the starch easier.
- The type and size of the starch impacts chemical reactions.

Refer to the reference page on granule sizes of various starches. Have students predict what each starch would do to impact the bioplastic properties.

*The smaller the starch pieces' surface area was to start with, the longer they take to rebind into a bioplastic. The smaller the surface area, the more pliable the final product is due to smaller starting polymer chains.*

# JOURNAL LOG

# JOURNAL LOG

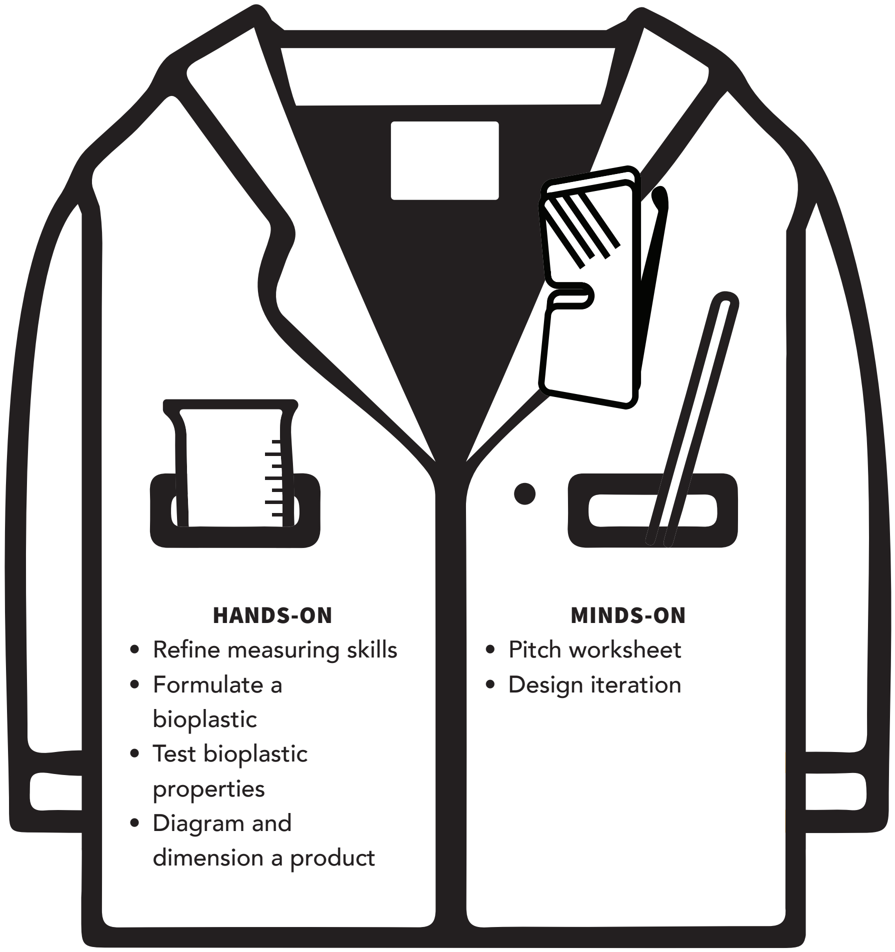
## MEETING 6: PROTOTYPE

### KEY TERMS

**Blueprint (n):** a design plan or technical drawing. Before computer-aided design, prints of plans were photographed in white on a blue background. This is the reason for the name **"blueprints."**

**Intellectual property (n):** a creative work originated in a person's mind that may be protected by law as patents (utility, design, plant) and trademarks by the U.S. Patent and Trademark Office and copyrights by the U.S. Copyright Office.

**Product hook (n):** a short phrase or jingle designed to entice consumers to purchase a product.




### TOOLS AND LAB EQUIPMENT

- Hot plate, 1 per student group
- Syringe, 1 per student group
- Aluminum tray, 1 per student group
- Heat-resistant gloves, 1 pair per student group
- 250-mL beaker, 1 per student group
- Protective gloves, 1 pair per student
- Protective goggles, 1 per student

### MATERIALS AND LAB SUPPLIES

- Wax pencil, 1 per student group
- Additives: white vinegar, baking soda
- Plasticizer: sorbitol
- Starches: tapioca, potato, corn
- Coconut oil
- Cookie cutter molds (various designs)
- Modeling clay
- Wax paper
- Your Student Guide

## PROCEDURE

This meeting will cover:

- Pre-Lab: Bioplastic **Blueprint**
- Lab: Creating Prototypes from a **Blueprint**
- Post-Lab Cleanup
- Write the **Hook**
- Reflection: Ready to Make Green!
- Journal Log
- Self-Assessments
- Indicators of a Successful Meeting

## PRE-LAB: BIOPLASTIC BLUEPRINT

Have students look back at their samples and identify what they will make with their samples and their unique properties. It is now time to create a bioplastic prototype based on students' results from the "Optimizing Our Bioplastic Invention" lab. During this meeting, teams will have three tasks to complete: blueprinting, pitch writing, and prototype creation.

1. First, groups will complete the Bioplastic **Blueprint** sheet. Students will draw a full-sized diagram of their bioplastic prototype and write the formulation for the bioplastic prototype. Have students look back at their samples and brainstorm as a group to identify what they will make with their samples. The Bioplastic **Blueprint** will be key as students enter the next phase.

   By blueprinting their ideas, students can claim this idea as their own! In fact, many of the components of a patent are present in the **blueprint** sheet. Patents are important because they allow one to claim the **intellectual property** of an idea. A patent allows the inventor to prevent others from profiting from their ideas. Patenting a process or product may be important when there is a unique idea about how to do something in a safer, more sustainable way.

### EDUCATOR NOTE

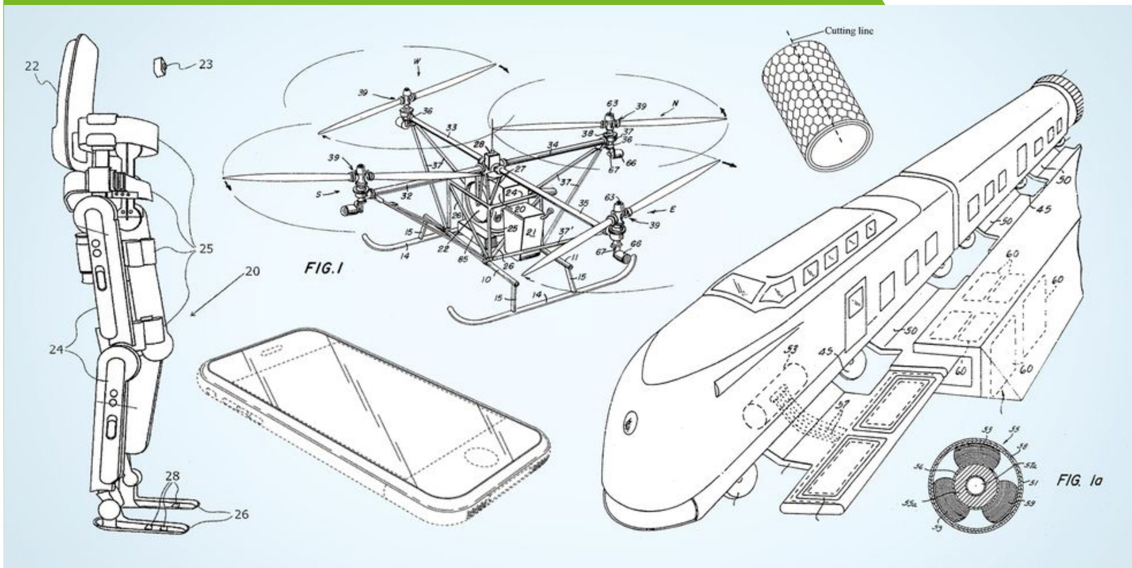
Review each group's Bioplastic **Blueprint** for approval.

2. After students complete the Bioplastic **Blueprint** sheet, they will move on to the lab to make a bioplastic prototype. Their bioplastic prototype will be the finalized bioplastic formulation molded into shape.

3. Finally, groups will consider the best way to communicate their invention—including the **product hook**—in preparation for the final meeting.

## EXTEND THE LEARNING

Patents provide detailed images of ideas before they become consumer products. Can you recognize the patent images for any of these products?




Images from 15 Patents that Changed the World, published in 2018. **Popular Mechanics**.

# BIOPLASTIC BLUEPRINT

**Goal:** ____________________________________________

**Product:** ________________________________________

**Properties:** ______________________________________

**Materials:**

____________________

____________________

____________________

____________________

____________________

____________________

____________________

**Procedure:**

1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.

**Diagram:**

## LAB PREPARATIONS

Before you begin, review the following safety rules as a class.

**LAB ROLES**

Have students decide the roles of each member of the group. Suggested roles are:

**Formulator**—responsible for chemicals

**Talker**—responsible for reading the procedure and communicating results

**Doodler**—responsible for recording observations

**Organizer**—responsible for setting up all non-chemical materials and for cleaning up glassware

Have students record their roles in their Student Guides. Remind them that they can take other roles in upcoming labs. Have students record their roles in their Student Guides.

**SAFETY**

1. Students and educators should wear gloves and goggles during labs from pre-lab setup to post-lab cleanup.
2. The bottles used with this lab are labeled "Lab Only." They should not be used for drinking purposes.
3. Be extra careful when using the hot plate.
4. Use heat-resistant gloves when handling the hot glassware.
5. Place warm glassware on the aluminum tray if the surface is not a lab bench.
6. Remember to turn off hot plates and all other heating devices after use.
7. Pour all components over a tray.

## REMINDERS

- Tell students to read through the lab before beginning.
- Have students organize all of the materials they will use at their lab bench or station.
- The formulation for their bioplastic prototype is based on their group's Bioplastic Blueprint sheet. It will be similar to the procedure from the previous trials of experimentation and optimization.

## LAB: CREATING PROTOTYPES FROM A BLUEPRINT

Have students evaluate the results from their Optimizing Our Bioplastic Invention lab trials as they enter the lab. This information will help them determine the final version of their bioplastic formulation.

1. Record the properties of the bioplastic, such as stickiness, hardness, brittleness, and flexibility.

   ___________________________________________________________

2. Did the properties change over time? How?

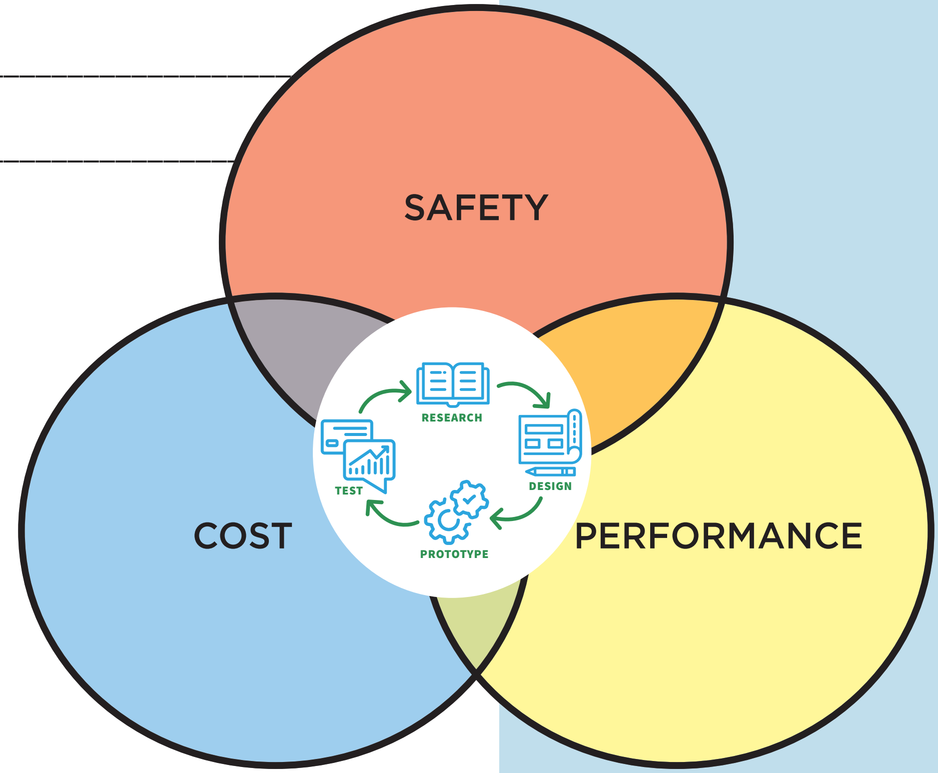
   ___________________________________________________________

   ___________________________________________________________

   Do the properties align with or differ from the group's goals for a product?

   ___________________________________________________________

   ___________________________________________________________




# MEETING 6

### EDUCATOR NOTE

The person handling the beaker must wear heat-resistant gloves.

The formulation for their bioplastic prototype is based on the group's Bioplastic **Blueprint** sheet. It will be similar to the procedure from their previous trials of experimentation and optimization.

Have students follow these steps in their Student Guides:

1. Fill in the Bioplastic **Blueprint** sheet with amounts and materials before you experiment.

2. Use the wax pencil to label your beaker with the plasticizer, additive, and starch you'll use.

3. Tape wax paper onto the tabletop.

4. Select appropriate molds (cookie cutter forms) for your prototype shape or make your own out of clay.

5. Apply coconut oil to wax paper and to the molds (cookie cutter forms or clay). This will help with removing the bioplastic once it hardens.

6. In your 250-mL beaker, use a teaspoon to measure 2 tsp. of your starch and 1 tsp. of your acid or base. Mix with the stirring rod.

7. Measure 2 tsp. of water and add to your beaker. Mix with the stirring rod.

8. Measure 2 tsp. of your plasticizer and add to your beaker. Mix with the stirring rod.

9. Mix the solution until uniform.

10. Using the hot plate and a timer, heat the solution on medium heat for 6–10 minutes, stirring for 15 seconds every minute until it starts to thicken.

11. Using your stirring rod, transfer the material from the beaker into the syringe.

12. Push the material as close to the end as you can.

13. Insert the plunger and flip the syringe upward.

14. Push out excess air.

15. Using your syringe, transfer the material from the beaker into your desired form.

16. Let your bioplastic material sit overnight to form.

17. Label your bioplastic prototype and set it on the tray to store for the next meeting.

## POST-LAB CLEANUP

- All materials are safe to pour down the drain.
- Wipe down your lab bench or tabletops.
- Clean beakers, teaspoons, and stirring rods in a warm, soapy water bath with 30 mL of vinegar added.
- Dry the tools and lab equipment, then store them properly in an educator-designated area.

*Students stirring their solutions on a hot plate.*

*Example of a lab-made bioplastic.*



### EDUCATOR NOTE

Remind students that Green Chemistry inventing is challenging, but inventing allows us to constantly make tweaks and adjustments to our ideas by further optimization. With more time, we could create an even more effective green chemistry invention.

*Student creating a bioplastic window cling.*

*Student group creating bioplastic walls to later use to build a prototype miniature house.*

MEETING 6

## WRITE THE HOOK

During this invention process, the focus has been on green chemistry criteria and using benign materials in order to minimize cost and safety risk. The benefits of green chemistry-inspired inventing are clear. Also, consumers desire materials that are safer for human health and the environment. With this in mind, have students consider how they can promote their product to potential buyers. Communicating the value of a product is an important component of inventing. After all, a life-changing invention can only change lives if people want to buy it.

Ask your students what makes their ideas for the invention unique. What need does the invention fill? Answering these questions will help students develop the **product hook** and tell the invention's story. It is important to be able to tell the invention's story. Have students complete the **Hook** sheet with their group. Ask students to incorporate how their group's invention addresses the challenges of traditional plastics and offers a unique alternative to a known product.

## REFLECTION: READY TO MAKE GREEN!

Congratulate your students on creating a prototype using an inventive bioplastic! Green chemistry invention is benign by design. This means that sustainability was considered during the entire inventing process.

Green chemistry inventions are judged based on three criteria: cost, safety, and performance. Think about what problem

## SELF-ASSESSMENTS

Collect the completed self-assessments as exit slips when students leave.

## INDICATORS OF A SUCCESSFUL MEETING

Students design and **blueprint** a bioplastic prototype, make a bioplastic prototype, and craft the companion invention story.

# HOOK

1. Why did you choose to make your invention?

2. What does it do?

3. Why is it useful?

4. What problem does it solve?

5. Who would use it?

6. Does it replace an object?

7. What makes it appealing to a consumer?

8. What makes it useful to a consumer?

9. What tools are needed to make the product?

10. What materials are needed to make the product?

11. Estimated cost of inventing?

12. What is your product's one-liner or hook to get a person interesting in it?

# JOURNAL LOG

# GREEN CHEMISTRY EDUCATOR GUIDE
## MEETING 7: COMMUNICATING IDEAS

### KEY TERMS

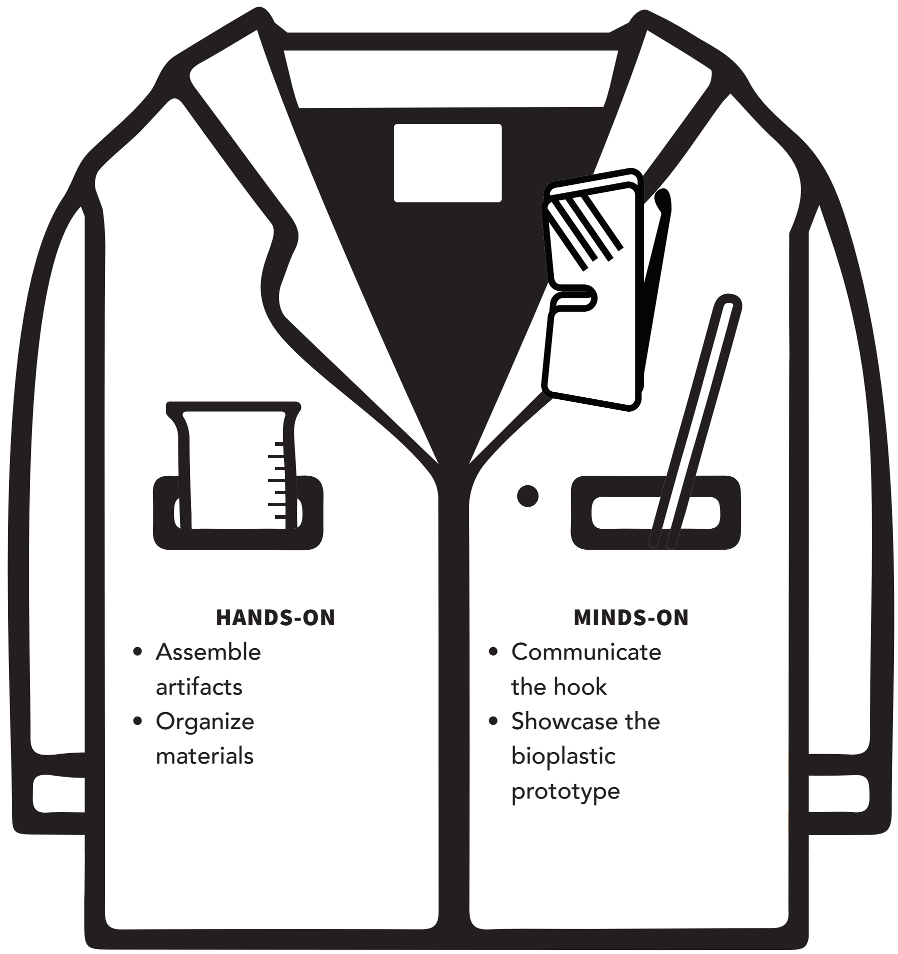
**Biodegradation (n):** the breakdown of material by microorganisms into natural substances.

**Feedback (n):** information received which can be used to improve something.

**Formulate (v):** to devise or develop; make.

**Peer (n):** one who is equal to you or belonging in the same group based on specific criteria such as age, schooling, or professional credentials.

**Peer review (n):** a process of evaluation of scientific, academic, or professional work by others working in the same field.




## MATERIALS AND LAB SUPPLIES

- Student Guides

## PROCEDURE

This meeting will cover:

- Meet the Inventor: Maher Damak, Lemelson-MIT Student Prize Winner
- Real-World Bioplastic Invention: Ooho
- Invention Statement
- Communicating with the Hook
- End of Life: Design for **Biodegradation**
- Reflection: Inventing with Green Chemistry
- Journal Log
- Self-Assessments
- Indicators of a Successful Meeting

## MEET THE INVENTOR: MAHER DAMAK, LEMELSON-MIT STUDENT PRIZE WINNER

Maher Damak received his PhD from the Department of Mechanical Engineering at the Massachusetts Institute of Technology (MIT). Science has always been one of Maher's passions, including the rigor of mathematics embedded within science and the beauty of physics, which turns natural phenomena into equations. Upon taking his first thermodynamics and electromagnetism courses and learning that a simple set of equations can explain the greenhouse effect, why water freezes, and why the sky is blue, he was convinced that scientific research was the right path for him.

Maher studied interfacial phenomena and fluid mechanics with Associate Professor Kripa Varanasi serving as his advisor. He invented a new technology that enhances the ability of agricultural chemicals being sprayed on plants to stick to the plants as intended, instead of rolling off into the soil. The technology is **formulated** with polymers that are biocompatible and **biodegradable** so they will not cause any additional pollution or health hazards. Maher earned the 2018 $15,000 "Eat it!" Lemelson-MIT Student Prize for his inventive work.

In addition to his education, Maher values community and mentoring as part of his life. One of his most rewarding volunteer experiences was in an economically challenged neighborhood in the suburbs of Paris. He spent eight months there working for Asphalte, a nonprofit association committed to helping immigrants integrate into French society. Maher assisted the children with their education. His responsibilities included mentoring a group of at-risk youth, helping them with schoolwork, organizing review sessions on various subjects, and hosting interactive sessions in which they could express their opinions and engage in critical thinking.

Maher is excited to pursue an entrepreneurial path to bring his inventions to market. He has already co-founded a company, Infinite Cooling. His company will commercialize a water-recovery invention and bring greater efficiency to the way power plants use water. Maher's invention will help to conserve this precious resource. As an entrepreneur, he plans to bring his technologies to those who need them, helping to mitigate some of the biggest problems

*Maher Damak invented a new technology that enhances the ability of agricultural chemicals being sprayed on plants to stick to the plants as intended, instead of rolling off into the soil.*

His company will commercialize a water-recovery invention and bring greater efficiency to the way power plants use water. Maher's invention will help to conserve this precious resource. As an entrepreneur, he plans to bring his technologies to those who need them, helping to mitigate some of the biggest problems that humanity faces in the 21st century.

**INVENTOR SPOTLIGHT**

One company working to reduce the number of plastic water bottles produced and consumed is **Notpla**. This is an innovative, sustainable packaging start-up company based in London. Ooho, the lab's first product, aims to change the disposable water bottle market with alternative packaging for water. Ooho packaging is made from plants and seaweed and will biodegrade in just four to six weeks—the same time that it takes for a piece of fruit to biodegrade. This bioplastic invention claims to utilize nine times less energy and produces five times less carbon dioxide than polyethylene terephthalate (PET), which is currently used for plastic water bottles. Best of all, Ooho packaging is not just biodegradable, but also edible. This invention aligns with green chemistry-inspired invention by designing for degradation and addressing the end of the product's life in the most sustainable way possible. What a novel approach: to reduce traditional plastics in the environment through applying green chemistry in inventing! **Check out Ooho's product hook video.**

EXTEND THE LEARNING

Plastic bottle production continues to increase. One study, as reported by the American Society of Engineering Education, stated that the production of plastic bottles will be more than 500,000,000 tons by 2021. Most plastic bottles are made out of polyethylene terephthalate (PET), which is recyclable. Unfortunately, many tons of bottles are not recycled and still end up in landfills or polluting the environment.

A team of inventors at the National University of Singapore's School of Engineering has found a way to turn plastic waste into a low-cost, lightweight PET aerogel that can be used for heat and sound insulation, oil spill clean-up, and as lightweight lining for firefighter coats. Are there ways to use green chemistry to plan for the use of recycled PET bottles?

## INVENTION STATEMENT

The invention statement focuses attention on the useful and unique aspects of the bioplastic. The statement can also focus attention on how and why the bioplastic was made. It targets a specific type of consumer or beneficiary. Writing an invention statement requires teams to succinctly describe their invention and place it within the greater problem space - it is harder than it appears!

Our JV InvenTeam green chemists are

_______________________________________________________________

_______________________________________________________________

The properties of the bioplastic include

_______________________________________________________________

_______________________________________________________________

It is useful for

_______________________________________________________________

(who is the user/consumer?)

because

_______________________________________________________________

_______________________________________________________________

_______________________________________________________________

(describe the need or problem)

It is unique because

_______________________________________________________________

_______________________________________________________________

_______________________________________________________________

(describe how it works or is different from other plastics)

The source materials we need to make our bioplastic are

________________ ________________ ________________

The process needed to make the product for consumers is

_______________________________________________________________

_______________________________________________________________

_______________________________________________________________

This process requires these materials and additional inputs

_______________________________________________________________

_______________________________________________________________

_______________________________________________________________

The estimated total cost to make our invention into a consumer product

is $ ___________________________________________________________.

## COMMUNICATING WITH THE HOOK

Being able to communicate with each other is important for sharing ideas. If someone cannot explain something clearly and succinctly, whether it be a story or an invention, the idea will not be understood.

Scientists work hard to communicate what they invent. Often, inventions and their underlying science are extremely complex and cannot be seen by the naked eye. Therefore, it is important for scientists to develop communication skills so they can share what they are doing in a way that the general public can understand the invention and discovery.

Inventing bioplastic solutions using green chemistry is both important and extremely complex. Bioplastics offer unique properties that allow products to be made from them. The bioplastic product can then be described to consumers. What is the best "hook" for consumers to learn about—and to consider buying—a product made using the principles of green chemistry?

Have students use the Invention Statement worksheet and their Hook sheet to prepare ways of communicating with others at the bioplastic prototype showcase. This is a type of communication, between technology and science, that often involves marketing and advertising. The hook will describe the students' invention to people who don't know about their product. It uses aspects of the Invention Statement and Hook sheets and incorporates green chemistry principles.

1. Refer back to the Hook sheet completed in Meeting 6.

2. Students groups should work to rewrite their answers to the guiding questions in one succinct paragraph.

3. Tell them to memorize the paragraph for quick and accurate descriptions of the product when asked about it.

4. Have students practice with **peer reviews.** They can share their hooks with **peers** and ask for **feedback** to ensure their hook is clear and understandable.

5. Students should consider other communications skills in addition to the verbal message. Communication skills and delivery of the verbal message improve with practice. Practice builds confidence. Remind students that their "body language" is also a skill to be developed. Body language supports the message delivered in the hook. Remind students that effective communicators always:

- Stand up straight,
- Minimize hand gestures and body movements,
- Make eye contact,
- Shake hands with a firm grip, and
- Smile!

*Student bioplastic creations including a heart stamp, teddy bear figurine, and a duck window cling.*

*Students sharing their bioplastic prototypes and communicating their ideas to each other.*

MEETING 7

## END OF LIFE: DESIGN FOR BIODEGRADATION

Green chemistry invention addresses a product's end of life through every stage of inventing. Students selected natural sources for their bioplastics and intentionally created materials that will **biodegrade**. Therefore, they have designed bioplastic prototypes that incorporate a plan for when the products cease to be functional and reach the end of their lives.

New materials—like bioplastics—are always being developed. Scientists, engineers, and inventors can have an impact on the environment when they create new materials and products. Green chemistry seeks to minimize negative impacts on the environment by introducing sustainable materials across industries. The bioplastics industry is just one of the fields utilizing green chemistry successfully. The global bioplastics market is expected to see 40% growth in production by 2030, reaching $324 billion in sales. This means that there are a lot of career opportunities in pursuing the scientific fields of chemistry, material science, and engineering.

The world of green chemistry is not limited to the lab, but overlaps with many other disciplines. It makes a difference if you support sustainable companies with your purchases and if you use your voice to share important ideas.

## EXTEND THE LEARNING

Did you know that the waste from shrimp, crab, and lobster shells is estimated to be six to eight million tons? Community college student, Jacob Couch, found this fact astounding. He put this into perspective. One ton, or 2,000 pounds, is equivalent to the weight of a polar bear or a sub-compact car. That's a lot of waste to throw away. Now, imagine keeping all of that waste out of landfills by turning the chemical components in the shells into something useful.

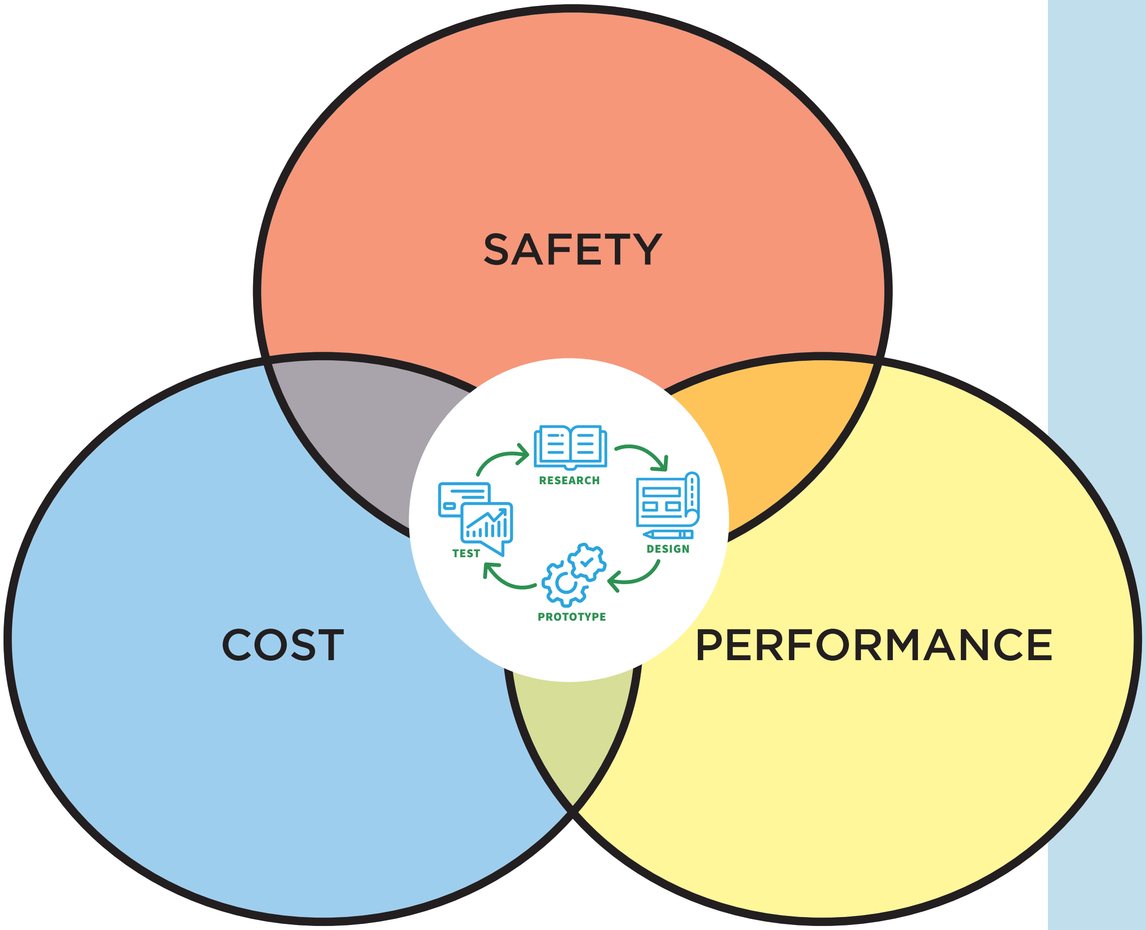
A group of students from the Royal College of Arts and Imperial College London in the United Kingdom experimented with one of the major shell components, chitin. Chitin is a nitrogen-rich biopolymer. It is one of the most abundant organic compounds on earth. It is also biodegradable. The college students designed machines that can make biodegradable and sustainable products out of chitosan, the active ingredient in chitin. Liquid chitosan can be molded or formed and dried to make packaging, containers, and sheets. Jacob remarked, "These students' inventions show that it is possible to create new and novel solutions by reusing waste. This new solution can help us get rid of single-use plastics that plague our environment."

*College students, inventors and entrepreneurs* **The Shellworks Team** *– turn chitosan into usable, sustainable products.* **Check out their YouTube video.**

## REFLECTION: INVENTING WITH GREEN CHEMISTRY

Have students use the last Journal Log for self-reflection on the green chemistry process, individual and group contributions to the JV InvenTeam, chemistry learnings, and ways of thinking like an inventor. They'll respond to the following questions in their Student Guides:

1. What ways of thinking and inventing have you developed in JV InvenTeams?
2. What skills and knowledge need further development?
3. What are some of your green chemistry goals for the future?



**EXTEND THE LEARNING**

There are many great green chemistry inventions. To read the latest news on how chemists are inventing green, visit the Beyond Benign newspage: **Chemists Invent Green.** By completing this guide and creating products with bioplastics, your students are contributing to the field of green chemistry through invention. If your students would like to share their experience or creations, have them tag @BeyondBenign and @LemelsonMIT on social media. Your class could be featured on the **Beyond Benign** website!

## SELF-ASSESSMENTS

Collect the completed self-assessments as exit slips when students leave.

## INDICATORS OF A SUCCESSFUL MEETING

Indicators of a successful meeting—and the JV InvenTeam Green Chemistry journey—may culminate in a showcase of prototype bioplastics and products. Each group can create a display that includes the prototype, invention statement, drawings, and Journal Logs as supports to communicate with invited guests during the last meeting. Students can talk with invited guests about the process they went through to create and optimize their prototype.

# JOURNAL LOG

## Green Chemistry

### Massachusetts Science and Technology/Engineering Standards - Middle School

| Meeting | Core Ideas | Physical Science Standards | Engineering Standards | Cross-Cutting Concepts | Practices |
|---|---|---|---|---|---|
| **Meeting 1: Invention Introduction** | ETS1.A<br>ETS1.B | | MS.ETS1-1<br>MS.ETS1-2 | • Structure & Function | • Asking questions and defining problems.<br>• Constructing explanations and designing solutions.<br>• Obtaining, evaluating, and communicating information. |
| **Meeting 2: Inventing for a Sustainable Future** | ETS1.A<br>ETS1.C<br>PS1.A<br>PS1.B | MS.PS1-2<br>MS.PS1-3 | | • Influence of Sciences, Engineering, and Technology on Society & the Natural World<br>• Cause & Effect<br>• System & System Models | • Asking questions and defining problems.<br>• Planning and conducting investigations.<br>• Constructing explanations and designing solutions.<br>• Obtaining, evaluating, and communicating information. |
| **Meeting 3: Reuse and Explore** | ETS1.B<br>ESS2.A<br>PS1.A<br>PS1.B | MS.PS1-2<br>MS.PS1-3 | MS.ETS 1-1<br>MS.ESS2.1 | • Influence of Sciences, Engineering, and Technology on Society & the Natural World<br>• Earth Materials and Systems | • Asking questions and defining problems. |
| **Meeting 4: Experimenting with Bioplastics** | ETS1.A<br>ETS1.B<br>ETS1.C<br>PS1.A<br>PS1.B<br>ESS3.C | MS.PS1-2<br>MS.PS1-3<br>MS.ESS 3-3 | MS.ETS 1-1<br>MS.ETS1-2 | • Structure & Function<br>• System & System Models<br>• Cause and Effect<br>• Influence of Sciences, Engineering, and Technology on Society & the | • Planning and conducting investigations.<br>• Constructing explanations and designing solutions.<br>• Developing and using models. |
| **Meeting 5: Optimizing our Bioplastic Invention** | ETS1.A<br>ETS1.B<br>ETS1.C<br>PS1.A<br>PS1.B | MS.PS1-2<br>MS.PS1-3 | MS.ETS1-1<br>MS.ETS1-2 | • Influence of Sciences, Engineering, and Technology on Society & the Natural World<br>• Structure & Function<br>• System & System Models<br>• Cause and Effect | • Asking questions and defining problems.<br>• Planning and conducting investigations.<br>• Developing and using models.<br>• Constructing explanations and designing solutions. |
| **Meeting 6: Prototype** | ETS1.A<br>ETS1.B<br>ETS1.C<br>PS1.A<br>PS1.B | MS.PS1-2<br>MS.PS1-3 | MS.ETS1-1<br>MS.ETS1-2 | • Influence of Sciences, Engineering, and Technology on Society & the Natural World<br>• Structure & Function<br>• Cause and Effect | • Developing and using models.<br>• Asking questions and defining problems.<br>• Constructing explanations and defining solutions. |
| **Meting 7: Communicating Ideas** | | | | • Influence of Sciences, Engineering, and Technology on Society & the Natural World<br>• Structure & Function<br>• Cause and Effect | • Obtaining, evaluating, and communicating information. |

## Green Chemistry

### Massachusetts Science and Technology/Engineering Standards - High School

| Meeting | Core Ideas | Physical Science Standards | Engineering Standards | Cross-Cutting Concepts | Practices |
|---|---|---|---|---|---|
| **Meeting 1: Invention Introduction** | ETS1.A<br>ETS1.B | | HS.ETS1-3 | • Structure & Function | • Asking questions and defining problems.<br>• Constructing explanations and designing solutions.<br>• Obtaining, evaluating, and communicating information. |
| **Meeting 2: Inventing for a Sustainable Future** | ETS1.B | | | • Influence of Sciences, Engineering, and Technology on Society & the Natural World<br>• Cause & Effect<br>• System & System Models | • Asking questions and defining problems.<br>• Planning and conducting investigations.<br>• Constructing explanations and designing solutions.<br>• Obtaining, evaluating, and communicating information. |
| **Meeting 3: Reuse and Explore** | ETS1.A<br>ETS1.C | | HS.ETS1-1 | • Influence of Sciences, Engineering, and Technology on Society & the Natural World<br>• Earth Materials and Systems | • Asking questions and defining problems. |
| **Meeting 4: Experimenting with Bioplastics** | ETS1.A<br>ETS1.B<br>PS1.B | HS.PS1-6<br>HS.PS2-6 | HS.ETS1-2<br>HS.ETS1-3 | • Structure & Function<br>• System & System Models<br>• Cause and Effect<br>• Influence of Sciences, Engineering, and Technology on Society & the | • Planning and conducting investigations.<br>• Constructing explanations and designing solutions.<br>• Developing and using models. |
| **Meeting 5: Optimizing our Bioplastic Invention** | ETS1.A<br>ETS1.B | HS.PS1-6<br>HS.PS2-6 | HS.ETS1-1<br>HS.ETS1-3 | • Influence of Sciences, Engineering, and Technology on Society & the Natural World<br>• Structure & Function<br>• System & System Models<br>• Cause and Effect | • Asking questions and defining problems.<br>• Planning and conducting investigations.<br>• Developing and using models.<br>• Constructing explanations and designing solutions. |
| **Meeting 6: Prototype** | ETS1.A<br>ETS1.B<br>ETS1.C<br>PS1.A<br>PS1.B | HS.PS1-6 | HS.ETS1-2<br>HS.ETS1-3 | • Influence of Sciences, Engineering, and Technology on Society & the Natural World<br>• Structure & Function<br>• Cause and Effect | • Developing and using models.<br>• Asking questions and defining problems.<br>• Constructing explanations and defining solutions. |
| **Meting 7: Communicating Ideas** | | HS.PS2-6 | | • Influence of Sciences, Engineering, and Technology on Society & the Natural World<br>• Structure & Function<br>• Cause and Effect | • Obtaining, evaluating, and communicating information. |

## Green Chemistry

### Massachusetts Science and Technology/Engineering Standards - Middle School

| Meeting | Technology/ Engineering Standards | Physical Science Standards | Practices |
|---|---|---|---|
| **Meeting 1: Invention Introduction** | 6.MS.ETS1-1<br>6.MS.ETS1-5<br>6.MS.ETS1-6<br>6.MS.ETS2-2<br>7.MS.ETS1-2<br>7.MS.ETS1-7<br>7.MS.ETS3-4<br>8.MS.ETS2-4 | | • Asking questions and defining problems.<br>• Constructing explanations and designing solutions.<br>• Engaging in argument from evidence.<br>• Obtaining, evaluating, and communicating information. |
| **Meeting 2: Inventing for a Sustainable Future** | 6.MS.ETS2-1<br>6.MS.ETS2-2<br>7.MS.ETS1-4 | 6.MS.PS1-6<br>7.MS.PS3-7<br>8.MS.PS1-5 | • Asking questions.<br>• Planning and conducting investigations.<br>• Analyzing and interpreting data.<br>• Constructing explanations and designing solutions. |
| **Meeting 3: Reuse and Explore** | 6.MS.ETS1-1<br>6.MS.ETS1-5<br>6.MS.ETS1-6 | | • Asking questions. |
| **Meeting 4: Experimenting with Bioplastics** | 6.MS.ETS2-2<br>6.MS.ETS2-3<br>7.MS.ETS1-7<br>6.MS.ETS1-6 | | • Developing and using models.<br>• Planning and carrying out investigations. |
| **Meeting 5: Optimizing our Bioplastic Invention** | 6.MS.ETS1-1<br>6.MS.ETS1-6<br>6.MS.ETS2-2<br>7.MS.ETS1-2<br>7.MS.ETS1-7 | | • Developing and using models.<br>• Planning and carrying out investigations.<br>• Constructing explanations and designing solutions.<br>• Obtaining, evaluating, and communicating information. |
| **Meeting 6: Prototype** | 6.MS.ETS1-1<br>6.MS.ETS1-6<br>6.MS.ETS2-2<br>7.MS.ETS1-2 | | • Asking questions.<br>• Developing and using models.<br>• Constructing explanation and defining solutions.<br>• Obtaining, evaluating, and communicating information. |
| **Meting 7: Communicating Ideas** | 6.MS.ETS1-6 | 7.MS-ESS3-4 | • Constructing explanations and designing solutions |

## Green Chemistry

### Massachusetts Science and Technology/Engineering Standards - High School

| Meeting | Technology/ Engineering Standards | Physical Science Standards | Practices |
|---|---|---|---|
| **Meeting 1: Invention Introduction** | HS.ETS1-3<br>HS.ETS1-6<br>HS.ETS2-1 | | • Asking questions.<br>• Constructing explanations and designing solutions.<br>• Engaging in argument from evidence.<br>• Obtaining, evaluating, and communicating information. |
| **Meeting 2: Inventing for a Sustainable Future** | HS.ETS4-1 | HS.PS3-1<br>HS.PS3-3 | • Asking questions.<br>• Planning and conducting investigations.<br>• Analyzing and interpreting data.<br>• Constructing explanations and designing solutions. |
| **Meeting 3: Reuse and Explore** | HS.ETS1-1<br>HS.ETS2-1 | | • Asking questions. |
| **Meeting 4: Experimenting with Bioplastics** | HS.ETS2-1 HS.ETS4-1 | HS-PS1-9(MA)<br>HS-PS1-11(MA) | • Developing and using models.<br>• Planning and carrying out investigations. |
| **Meeting 5: Optimizing our Bioplastic Invention** | HS.ETS1-3 HS.ETS1-6<br>HS.ETS4-1 | HS-PS1-9(MA)<br>HS-PS1-11(MA) | • Developing and using models.<br>• Planning and carrying out investigations.<br>• Constructing explanations and designing solutions.<br>• Obtaining, evaluating, and communicating information. |
| **Meeting 6: Prototype** | HS.ETS1-2 HS.ETS1-3<br>HS.ETS1-6 | HS-PS1-9(MA) | • Asking questions.<br>• Developing and using models.<br>• Constructing explanation and defining solutions.<br>• Obtaining, evaluating, and communicating information. |
| **Meting 7: Communicating Ideas** | | | |

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# ACKNOWLEDGEMENTS


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