Are You Ready to Rock?! Heavy Metal Contamination and Remediation in Water and Soil

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Host Organization: **Stanford University**   ETP Type: **Traditional**
Subject/Grade: **Integrated Science / 7th & 8th Grade**

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Abstract (~150 words)

The contamination of water and soil by heavy metals poses a serious environmental problem with severe consequences for health. In this lesson, students will learn the significance of the presence of heavy metals in the environment around them and pursue an investigation that models the methods scientists use to remove these toxins from water. First, will grow pea plants in contaminated and control soil samples to illustrate the detrimental environmental effects caused by the presence of heavy metals. Next, students will engage in a macro-sorting activity and reading passage to build their understanding of why scientists must develop novel ways to filter and sort substances. Finally, students participate in a paper chromatography investigation, to emulate the spectroscopy detection methods scientists use in their laboratories.

Focal Content & Supporting Practices

NGSS: **MS-ESS3-3**
Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.*
[Clarification Statement: Examples of the design process include examining human environmental impacts, assessing the kinds of solutions that are feasible, and designing and evaluating solutions that could reduce that impact. Examples of human impacts can include water usage (such as the withdrawal of water from streams and aquifers or the construction of dams and levees), land usage (such as urban development, agriculture, or the removal of wetlands), and pollution (such as of the air, water, or land).]

21st Century Skills and Applications (1 - 2)

Problem Solving
- Accurately identifies, breaks down, and analyzes problem
- Produces thorough analysis of effects and tradeoffs for various alternatives
- Addresses problem in greater context, including contributing factors and long-range effects

Communication and Collaboration
- Written and oral communications are clear, correct, and concise
- Listens carefully; asks questions that effectively clarify or spark additional ideas
- Assumes shared responsibility for collaborative work and values the contributions of each team member

Students will learn about how pollutants and contaminants impact the environment, will strategize how scientists choose the best tools for their jobs, and communicate their findings.

Measurable Objective(s)

- Students will be able to **model real-world implications** of heavy metal contamination by growing pea plants in contaminated & control soil samples and constructing a lab report conclusion that **communicates the need to monitor and minimize this human impact** on the environment
- Students will be able to **conduct a scientific investigation** on thin layer chromatography, determining how to separate substances in a solution and identify different compounds, modeling the ICP Spectroscopy used in the laboratory. Students will **compare and contrast** the movement of each different substance through capillary action. [ways to separate mixtures - how scientists do this in the lab]

Formative Assessment(s)

<u>After growth of pea plants in control/contaminated soil:</u>
30-Second Share: Many students take a turn to report something learned in the lesson for up to 30 seconds each. Connections to the learning targets or success criteria are what the teacher is looking for in the language used by the student. Give chance for all students have the opportunity to participate, share insights, and clarify what was learned.

<u>After human impact reading activity:</u>
3-2-1: At the end of the learning, this strategy provides students a way to summarize or even question what they just learned. Three prompts are provided for students to respond to: 3 things you didn't know before, 2 things that surprised you about the topic, 1 thing you want to start doing with what you've learned

<u>After paper chromatography investigation:</u>
One-Minute Paper: This might be considered a type of exit ticket as it is typically done near the end of the day. Students, either individually or with a partner, are asked to respond in writing to a single prompt. Typical prompts include: Most important learning from the day/Most surprising concept/Most confusing topic and why/Identify something you think might appear on a test or quiz

Summative Assessment(s)

Students will write up a robust lab report demonstrating their knowledge and skills gained in this lesson. Lab report will include the following: Pea Plant Assay Analysis, Macro-Sort Investigation, Reading Activity, Chromatography Lab, & Summative Analysis. Lab report will be assessed on accuracy of data represented as well as quality of science communication and use of science-writing conventions (CER format)

Fellowship Description (300-500 words)

The Cui Lab at Stanford University (who they are) focuses on an integrated approach to Materials Science, finding novel solutions to a variety of real-world problems in their research. When the size of materials is reduced to the nanoscale dimension, physical and chemical properties can change dramatically. In addition, nanostructures also afford new exciting opportunities of low-cost processing. The lab is interested in a broad range of nanoscale properties including electronic, photonic, electrochemical, mechanical, catalytic and interfacial properties. Understanding these properties has important technological implications in energy conversion and storage, electronics, biotechnology and environmental technology. The Cui Lab studies fundamentals of nanomaterials including nanowires, colloidal nanocrystals and patterned nanostructures, develop low-cost processings and address critical issues in real-world applications.

In my fellowship, my focus as an Environmental Tech was to study novel ways to remove heavy metals from the environment, specifically deposits found in water and soil. Contamination of soil and water by heavy metals can be toxic, making this an important environmental problem with severe consequences for people and the planet. Some of the work my lab group has already done in this field includes developing advanced technology to solve environmental problems such as organic wastewater treatment, indoor formaldehyde removal, experiments on materials synthesis and using electrochemistry to remediate soil. I was able to join the group in their research on using asymmetrical alternating current electrochemistry (AACE method) to remove the heavy metals copper, lead, and cadmium from contaminated soil samples. This method improves upon previous methods of soil remediation as it provides removal of toxins at a much faster speed and limited chemical cost, while also eliminating soil nutrient loss, making the soil sustainable and safe for agricultural use. My research this summer took this novel method a step further, studying the effectiveness of the AACE method on a soil sample from Hong Kong contaminated with arsenic, in addition to the previously studied heavy metals.

Fellowship Connection to School/Classroom (300-500 words)

Science is a launchpad to the future. The students in my classroom today **are** the people that will solve the problems of tomorrow. Many of those problems will find their solutions in the worlds of science, technology, engineering, and mathematics. By completing this fellowship, I have been provided direct access to what the work of solving problems looks like in a laboratory. I now have hands-on experience working with electrochemistry to solve environmental problems, I understand how to collect and analyze laboratory data, and compare and contrast the efficiency of a variety of problem-solving methods. However, it is in sharing these experiences that their true power is realized. In this ETP lesson, my students will use techniques similar to what I accomplished in the Cui Lab to utilize chemistry to improve the environment. Throughout the three-day lesson, I will highlight these connections to make it clear to my students how the work I did during my fellowship relates to our learning. Additionally, I plan to share a photo-diary of my Stanford Lab experiences with my students and their families to illustrate the expansive opportunities that are available to my students in their future studies. I am excited by the idea of using my research to demonstrate that there are infinite routes that can be taken to make the world a better place, and that environmental science isn't exclusively a biological focus- so much change can be made using the tools of chemistry, engineering, and more. I look forward to sharing my research with my students and their families by presenting my poster at our Back-to-School Night in the fall, which will not only demonstrate the work I did over the summer but also model for my students the power of science communication. Finally, I hope to use this research and the work from my ETP to inspire a new era of environmental consciousness at my school campus. This fellowship will inform and inspire the work of my new Environmental Justice Club- a group of brilliant students dedicated to making our school and the people in it more sustainable through makery, recycling, and habitat restoration in our local community. My fellowship at Stanford University has provided the foundation, but it is only the beginning of this exciting work.

Instructional Plan (This is the bulk of your ETP and may take several pages.)

Day 1:

Framing the Learning *(rationale for students)*

This introduction section provides students with an opportunity to understand the research completed during the Stanford Lab Fellowship

Introduction: The purpose of our investigation is to learn about how our water and soil can be contaminated, explore how these contaminants can be removed, and examine the impacts this pollution can have on living things in the ecosystem. We will do this in three ways: growing and comparing the health of pea plants in contaminated and non-contaminated soil samples, sorting substances at the macro-level to inform how substances are filtered at a microscopic level, and by investigation during the chromatography lab.

[note: many of the chemicals and materials used during the fellowship are toxic or inaccessible. For this reason, students will not be using actual heavy metals in their investigation, but rather modeling techniques for their detection and remediation using everyday materials or lab kits. However, at each step students will learn about how that component relates to what Materials Scientists and Environmental Chemists are doing in the cutting edge of today's research]

Our Big Questions to Explore:

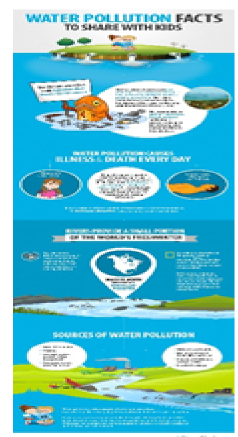
1) Why is contaminated soil harmful to the environment?
2) How do scientists choose the right tools to help the environment?
3) What responsibility do humans have to prevent/remediate pollution in the future?

Overview of Lesson Segments:

Warm Up – 5 mins – Connecting to the real world

Pea Plant Assays – 20 mins – Grow and measure pea plants in experimental vs. control soils

Macro-Sort & WhiteBoarding – 65 min – Modeling filtration techniques & designing investigation



Warm-Up:

[Infographic](https://images.app.goo.gl/VFeLLrmwgueN3EY76) Analysis Activity: students actively read an infographic & share their thinking with their team

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https://images.app.goo.gl/VFeLLrmwgueN3EY76

Pea Plant Assays:

Framing the Learning *(rationale for students)*

The pea plant assays allow students to see in real time what effects pollution and heavy metal contamination have on the environment & health of organisms

Procedure:

1. Gather all of the materials needed to perform the experiment.
2. Create 3 pots- one with each type of soil. LABEL each clearly: control, contaminated, and cleaned.
3. Double check label on each pot of soil with the treatment type, name of person in lab group, and cohort.
4. In the first pot, poke 10 holes in the soil WITH A PENCIL that are 1 ½ inches deep. Be sure that the holes are evenly spaced from each other and the walls of the pot.
5. Place 10 of the green bean seeds in the soil, one in each of the holes. Use gloved hands to smooth soil over the seeds.
6. Repeat steps 4 & 5 for the other two pots of soil.
7. Water all three pots with 10ml of water each, and place on the cart which will be moved to a sunny, well-lit area.
8. Record the seed germination rate and other observations in the three pots over a three day period.

Macro-Sorting Activity and WhiteBoarding:

**this lesson does not provide explicit direction on teaching students to WhiteBoard. Please see supplemental links for more information*

Students will complete a sorting activity, determining the best tools and methods to separate individual substances from a larger mixture. Students will first receive a clear mason jar full of the “mixture”- allowing them to see (but not touch yet!) the types of substances they will be required to sort. Then, they will WhiteBoard- brainstorm their experimental method, determining the best tools and methods for separating their mixture into its individual components. Then, students will use their tools to sort!

Framing the Learning *(rationale for students)*

In the lab, scientists must frequently make decisions about the best tools to use for their investigations. This includes filtration techniques at the microscopic level. In the macro-sort, students are able to see why choosing the best tools and methods are important

[Introductory Mini-Lecture for Part 1:

In this lab we will learn about some ways in which different substances are separated. In chemistry and engineering, a separation refers to a process that we use to separate components of a mixture from one another. This may sound fancy, but you see and perform separations in everyday life all the time.

For example, you use a strainer to separate water from pasta after you are done cooking your favorite spaghetti dish. In this case, the strainer acts as a separation device that takes in a mixture of water, cooked pasta, and perhaps a bit of salt and separates them into two distinct components: the water and dissolved salt which flow through the strainer, and the cooked pasta which cannot fit through the holes in the strainer and thus stays behind.

Now, we must consider the something called the basis of separation. The basis of separation is a property which differs among the components of the mixture that we take advantage of in order to separate those components. In the pasta example, the basis of separation was size; the salt water solution is a liquid and thus flows through the holes in the strainer without a problem, while the spaghetti strands are much too large to fit through the strainer holes. Can you think of some other properties we could use as a basis of separation? (Examples include appearance, density, solubility, charge, magnetism, and boiling temperature.)

When scientists and engineers are given a mixture and asked to isolate the product they're interested in — for example, chemists who have made a promising new medicine and need to separate that molecule from all the other side products — they think about the properties of the different components of the mixture to see if any of these properties can be used as a basis of separation.

Today, you will be given a mixture of items and asked to separate them into seven individual components using any number of a wide variety of tools at your disposal. You'll recognize some of the components of the mixture with your naked eye, while some of the others will seem indistinguishable. Just remember to consider which basis of separation your tools can take advantage of and work from there!]

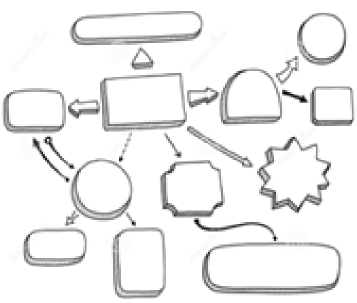
Part 1: Plan Your Sort

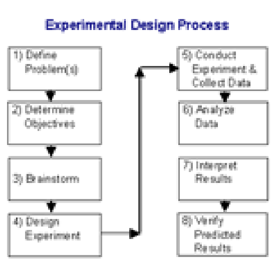
> Take 1 minute to LOOK at your mason jar WITHOUT talking. Make sure to pass the jar to each member of your lab team, so everyone has a chance to see all of the components.

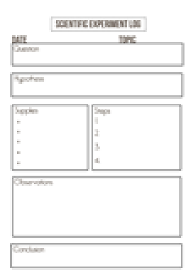
> Next, take 2 minutes to TALK to your team about what you notice and what you wonder. No need to write things down yet, just talk it out.

> Then: WhiteBoard your strategy with your team. What tools will you use for this mixture? How will you separate larger vs. smaller components? What are the advantages and disadvantages of each tool? How will you involve all members or your team?

Ideas for brainstorming below, but students are free to express their ideas in writing any way they would like:







Order	Item	Basis of Separation	Tool
1			
2			
3			
4			
5			
6			
7			

Part 2: Sort Your Substances!

Using the ideas you and your team developed, sort your substances! Your goal is to sort as QUICKLY and as CAREFULLY as possible! You should have 7 neat, homogenous piles when you are done!

Teacher Set-Up Instructions:

Note: You will want to have this puzzle set up ahead of time for each group so that they won't know what the individual components of the mixture are before they start.

1) Measure out the following substances for each group (all quantities/amounts approximate): 3 ping pong or golf balls, 1 cup of red beans (optional: mix a few pinto beans in with the red beans), 3 tbsp. of grape nuts, and 1 tsp. Salt.
2) For each group, chop up enough flat toothpicks into small pieces (each approximately the size of the tip of a sharpened wooden pencil) to be able to give each group ¼ tsp.
3) Chop up a steel scrub brush into enough small iron filings (each approximately the size of the tip of a sharpened wooden pencil) to be able to give each group a pinch.
4) Mix the substances from steps 1-3 in a large cereal bowl for each group.
5) Lay out the following essential tools on the table on which the students will be working: tongs, a colander, tweezers, a fine strainer, a magnet, napkins or paper towels, ~20 oz. of water in a bottle, a spoon, and at least three more large bowls.
6) Mix in as many of the "decoy" tools with the essential tools as possible; see the materials section for ideas.

Part 3: Reflect on Your Success
Thinking about your sorting activity, answer the following questions with your team in your lab packet:
> Which tool did you use to try to separate your first item of choice? Why did you choose that item? Were you successful?
> Which item seemed most different from the others? What was the basis of separation that you used to remove this item from the mixture?
> What was the easiest part of this task? What was the hardest part?
> Let's say that you're given a mixture of salt dissolved in water. Can you think of any basis of separation you could exploit to separate the salt from the water?
> Name two real-life examples of separation processes and the basis of separation for each.
> How does this task relate to what scientists have to do in their laboratories? How do you think scientists pick the best tools for their jobs? What factors must they consider in a task like this?

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Day 2:

Overview of Lesson Segments:

Warm Up – 5 mins – Review of take-aways from Sorting Activity
Reading Activity– 25 mins – Understand human impact & need for remediation
Chromatography Lab – 60 min – Separate substances from a mixture, thin layer chromatography

Warm-Up:
Connections and Relationships Activity: students reflect on their investigation from Day 1 & agree on key take-aways

> **Framing the Learning** *(rationale for students)*
> In the reading activity, students are able to access the bigger picture context of why this research is so important, and exactly what impact this has on the environment

Reading Activity:
Students will receive a copy of "Heavy Metals & Human Impact" In pairs, students will actively read their passage. After reading, students will participate in a class discussion of key take-aways.
Active reading guidelines:
1) Think as you read! Pay attention to what you do/don't understand.
2) Mark the text as you read! Write in the margin, underline, and highlight important information.
3) Pay attention to pictures! Read all figures and their captions – don't skip parts.
4) Talk about what you read! After you are done talk to your partner about what you read.

> **Framing the Learning** *(rationale for students)*
> The chromatography lab models the ICP spectroscopy used in research labs. It demonstrates how one can separate specific chemicals or substances from a solution to determine the composition of that solution. This is similar to spectroscopy, which separates and detects the exact composition of substances in a lab.

Thin Layer Chromatography Lab:
[Introductory Mini-Lecture for TLC Lab:

Now that we have had some practice taking advantage of various bases of separation to separate a mixture into its individual components, we are going to learn how to use a powerful separation technique called chromatography which *can separate compounds that are quite similar to one another.* ***Chromatography*** *is a general type of separation in which a mixture of compounds passes through a* ***stationary phase****. Different compounds have different relative affinities for the mixture traveling along the stationary phase, or the* ***mobile phase****, and the stationary phase, causing these compounds to separate from one another. More specifically, we're going to use a technique called* ***thin layer chromatography (TLC)****, which separates components of liquid mixtures based on polarity.* ***Polarity*** *refers to the separation of charge in a molecule — in other words, how unequally the electrons in a molecule are shared among the different atoms.*

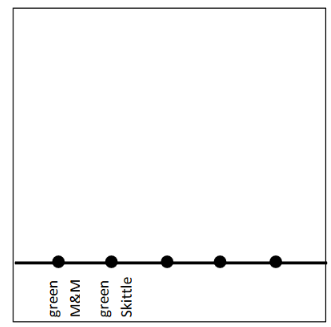
For this experiment, the stationary phase will be a coffee filter, while the mobile phase will be rubbing alcohol. The dyes from the coatings of M&M's and Skittles will be carried varying distances along the coffee filter by the rubbing alcohol, allowing us to visualize the many different dyes that are used on the surface of each piece of candy. For this TLC experiment, the more polar the compound, the greater attraction it will have for the mobile phase and the farther up it will be carried by the mobile phase. Conversely, the more nonpolar the compound, the weaker the attraction it will have with the rubbing alcohol.

[For teacher's information only: this separation of positive and negative charge is dependent on the electronegativities of the atoms within a molecule. An atom is comprised of a nucleus containing positive charges and neutral charges and outer rings of negatively charged electrons. The outermost shell of electrons is called the valence shell. The electronegativity of an atom is the tendency of an atom to attract electrons to itself based upon properties such as the distance the valence electrons of an atom are away from the positive charges in the nucleus.]

Before we start, we should talk about what makes the mobile phase move in the first place. In TLC, the mobile phase moves uphill due to a phenomenon called capillary action, which we see in everyday life when a paper towel absorbs a liquid. ***Capillary action*** *occurs when a liquid moves uphill against gravity due to interactions between the stationary and mobile phases.]*

http://labsci.stanford.edu/images/Chromatography-S.pdf

Procedure:



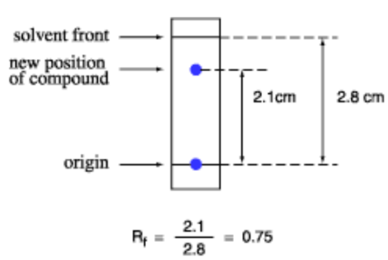
In this lab, you will use thin layer chromatography (TLC) to separate the individual dyes from M&M's and/or Skittles, as well as observing the different colors that make upblack ink. In this experiment, coffee filter paper will be the stationary phase, while a solution of rubbing alcohol will serve as the mobile phase.

1. Cut the coffee filter paper into two 3 inch x 3 inch squares, one for candy and one for ink.
2. For each square, lightly draw a pencil line ½ inch from the edge of one side of the paper.
3. For the candy filter square, make a pencil dot for each color to be used along the line about ¼ inch apart and label each dot (see diagram to the right) > >
4. Remove the color (dyes) off the candies you choose to analyze by placing each candy in a piece of foil and adding 6 drops of water.Try to select pairs of candies of the same color (e.g., green M&M's and green Skittles, orange M&Ms and orange Skittles, etc.)
5. While you are waiting for the candy dye to dissolve, prepare your ink filter square.Make a small dot (approx. 2mm diameter) with each marker along the pencil line about ½ inch apart and label each dot.
6. For the candy filter square, dip a toothpick into each colored mixture left behind in the foil and dab the color on the corresponding pencil dot on the filter paper. Allow the filter paper to dry and add more color to each dot. Repeat so that you have added color to the dot three times.
7. When the papers are dry, fold in half so that they stand up on their own. Make sure that the fold is vertical, leaving the line with the dots near the bottom edge of the paper.
8. For each filter, pour rubbing alcohol (isopropyl alcohol) into a clean tall glass to a liquid level of 1/4 in. Then stand the filter paper inside the glass with the sample side down and the edge of paper wetted by the developing solution. Make sure that the alcohol level is below the line of the samples.
9. Observe as the rubbing alcohol progresses up the paper by capillary action. When the rubbing alcohol is ¼ inch from the top edge of the paper, remove the paper from the glass and let dry.

The retardation factor (Rf) is the distance traveled by the compound divided by the distance traveled by the solvent front:

$$R'' = \frac{\textit{distance traveled by the compound}}{\textit{distance traveled by the solventfront}}$$

See the following example:



http://labsci.stanford.edu/images/Chromatography-S.pdf

If you could repeat this experiment under exactly the same conditions, the Rf values for each sample would always be the same!

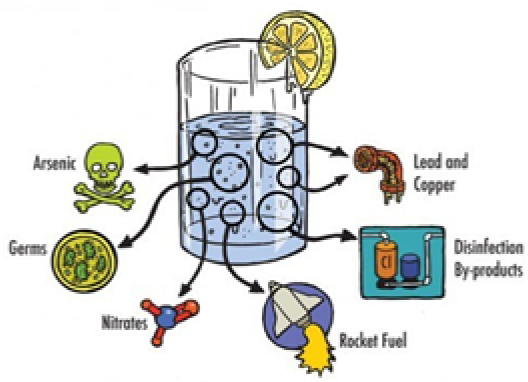
Day 3:

<u>Overview of Lesson Segments:</u>

Warm Up – 5 mins – Image Analysis and review of take-aways from Chromatography Lab & Pea Plants
Lab Report & Analysis – 55 mins – Complete written lab report

<u>Warm-Up:</u>

Image Analysis Activity: students complete



Guide: How to analyze an image?

Observe	Reflect	Question
What did you notice first? Describe what you see. What is being shown? How is it displayed? Is it mostly images or words?	Why do you think this image was made? What is happening in the image? Who do you think the audience is for this image? What can you learn from examining this images?	What do you wonder about when looking at this image? You can start questions start with "Who," "What," "When," "Where," "Why," "How," "I wonder"
Write a caption for the image.	How does this relate to students who struggle?	How could you use this type of observation support in your classroom?

Based on Library of Congress Teacher's Guide to Analyzing Photographs and Prints http://goo.gl/AnalyzingGuide

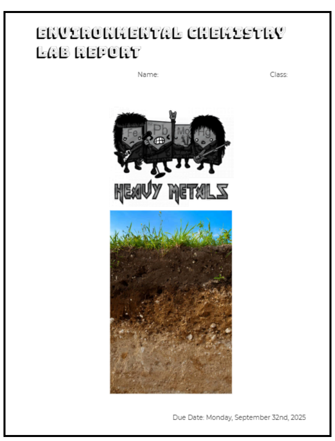
<u>Lab Report:</u>

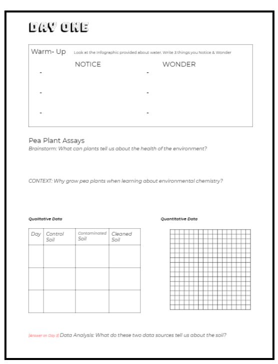
Students have group work time to work in their teams to complete their written lab report, which functions as their summative assessment.

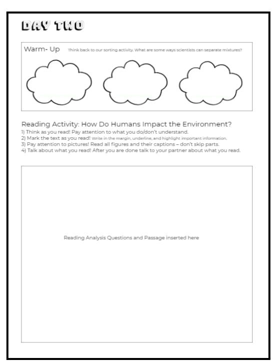
(Selected Pages of Lab Report Below)

Framing the Learning *(rationale for students)*

Students are able to compile & reflect on all of their learning in the lab report







Supply List

Materials:

- Ping pong or golf balls (at least three per group of 3-4 students)
- Tongs
- Red beans (preferably 1 cup per group); a few pinto beans optional
- Colander (with holes large enough to let grape nuts through but not beans)
- Tweezers
- Salt (1 tsp. per group)
- Fine strainer

- Steel scrub brush
- Scissors
- Magnet (any old classroom magnet should do the trick)
- Napkins or paper towels
- Grape nuts cereal (3 tbsp. per group)
- Flat toothpicks (at least four per group)
- Water in a cup or bottle (at least 20 oz. per group) and access to a water source
- Spoon
- Three large bowls
- M&M's and Skittles
- Coffee filter paper
- Water
- Rubbing Alcohol
- Pencil
- Scissors
- Ruler
- Toothpicks
- Aluminum foil
- 2 clear drinking glasses
- 30 green bean seeds
- soil samples: control, contaminated, and cleaned
- distilled water
- pipet
- masking tape

References

Chromatography: Candy Coating and Marker Colors Teacher Version. (n.d.). Retrieved July 01, 2019, from http://labsci.stanford.edu/images/Chromatography-T.pdf

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Guide: How to analyze an image [Digital image]. (n.d.). Retrieved July 07, 2019, from https://docs.google.com/document/d/1psUnKK2aQysp6lzkwoCGcWn1wO69I8FERnJ_rXbf4mw/edit

Xu, J., Liu, C., Hsu, P., Zhao, J., Wu, T., Tang, J., . . . Cui, Y. (2019). Remediation of heavy metal contaminated soil by asymmetrical alternating current electrochemistry. *Nature Communications,10*(1). doi:10.1038/s41467-019-10472-x

Keywords

environmental chemistry | environmental science | water quality | water and soil remediation | heavy metal pollutants | pollution | contaminants | materials science | electrochemistry | lab science

Links to Files in this ETP

Student Handout
Student Slides
Student Reading
Possible Student Responses
Folder with all ETP Files