**Writing the Principles**

**HIGH SCHOOL**

**Green Chemistry & Sustainable Science**

**Teacher Background Information:** For more information on the 12 Principles of Green Chemistry and how to introduce and explain them to your students go to the last pages of this document.

**Goal:** To introduce students to the 12 Principles of Green Chemistry and how it relates to a chemical process.

**Student Objectives:** Students will…

* Understand the basics of the 12 Principles of Green Chemistry.
* Use weight and measurement to understand the concept of a recipe as it is applied to a chemical process.
* Think critically about a process and how it might be improved.

**Materials (per lab group):**

* Skim milk powder
* Water (tap is fine)
* White Vinegar
* Baking Soda
* Filter paper
* 2 x 200 ml beaker
* Plastic spoon
* Wooden stir sticks
* Can of beets
* Bleach wipes
* Hot plate
* Thermometer
* Erlenmeyer flask
* Isopropyl alcohol wipes
* 0.5 g glitter
* Balance
* Safety glasses
* Gloves
* Lab procedure sheet
* Revised lab procedure sheet

**Time required:** 45–60 minute class period

**NGSS Standards Met:**

* **HS-PS1-2.** Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns in chemical properties.
* **HS-PS1-5.** Apply scientific principles and evidence to explain how the rate of a physical or chemical change is affected when conditions are varied.

**Green Chemistry Principles Addressed:** 1–12

**Procedure:**

NOTE

***Be sure to check for food allergies in the students with whom you intend to do this lesson.***

Students will soon realize that it is poorly written as it involves a lot of waste and silly procedures that are not needed. Take your cue from the students and stop the process and begin the rewriting process whenever you feel it is appropriate.

PREP

* Gather all materials and set up balance stations if you don’t have enough for each group.

IN CLASS

* Explain to the students that they will be in the role of materials scientists creating an adhesive. The purpose is to create a useful product and learn about the 12 Principles.
* Split students into lab groups and hand out copies of the lab procedure.
* Allow students to complete the lab and create their glue.
  + Students will most likely begin to exclaim that it is really stupid and that it doesn’t make sense. Get to the end of the lab if you can.
* Optional: have students complete the properties of matter sheet on the glue they made
* Tell the class that you agree that some of the steps seem wasteful, dangerous, unhealthy, or unnecessary.
* Hand out the Revised Lab Procedure sheet. Give students time minutes to rewrite their step and let them know that they will be asked to explain why they changed their step and why it is beneficial.
  + Tell them also to take a look at the things they will need at the beginning of the recipe as they may need to make some changes there as well.
* Have students share their revised step with the class.
* Ask students to brainstorm a list of ways that their new version either minimized the impact on the Earth or maximized the conservation of energy or materials. Write these ideas on the board.
* Explain to the students that they just used the 12 Principles of Green Chemistry without knowing it.
* Give each student a copy of the 12 Principles of Green Chemistry.
* Explain that they may find them difficult to read because the Principles are used in very complex scientific processes but that the process is the same as the one they just went through.

**Writing the Principles: Lab Procedure**

**You will need:**

* Skim milk powder
* Water (tap is fine)
* White Vinegar
* Baking Soda
* 2 x 200 ml beaker
* Plastic spoon
* Wooden stir sticks
* Tongs
* Can of beets
* Bleach wipes
* Hot plate
* Thermometer
* Erlenmeyer flask
* Isopropyl alcohol wipes
* 0.5 g glitter
* Safety glasses and gloves
* 15ml centrifuge tube

**Procedure:**

1. Put on your safety glasses and gloves
2. Measure 200 ml of skim milk into a 200 ml beaker.
3. Put 100 ml of the milk into another 200 ml beaker. Discard the leftover milk.
4. Select four slices of beets and place them in the milk. Place the remaining beets in the trash to be discarded.
5. Swirl the beets and milk mixture for 30 seconds using a plastic spoon.
6. Remove the beets from the milk with tongs and discard them. Your milk should now be a nice reddish pink color.
7. Measure 15 ml of the vinegar into a 15 ml centrifuge tube and place in the fume hood for 20 seconds.
8. Warm the milk to 45°C
9. Add the 15 ml of vinegar to the beaker with the milk.
10. Gently heat and stir using a plastic spoon
11. As soon as it curdles remove it from the heat
12. Decant the liquid from the solid into the waste container while your lab partner recites the alphabet backwards.
13. The solid that you have left is called Casein. Wash the casein with an isopropyl alcohol wipe to remove any traces of vinegar.
14. Add a 4.75 grams of baking soda, 0.5 g glitter, and stir with a stir stick
15. Add 30 ml of water and then let the mixture stand for a few days in a dry climate so that some of the water evaporates and you get the correct consistency of glue.
16. Using bleach wipes, thoroughly clean your work station.

**Writing the Principles: Revised Lab Procedure**

**You will need:**

**Directions:**

1.

2.

3.

4.

5.

6.

7.

8.

9.

10.

11.

12.

13.

14.

**Writing the Principles - Teacher Answer Key**

Below are the 12 principles and changes to connect the lab rewrite to the 12 Principles of Green Chemistry:

1. It is better to prevent waste than to treat or clean up waste after it is formed.

Throwing away the excess milk and other consumables. Using too much of something. Only use the amount you really need so that you do not generate waste.

2. Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

Throwing away of the filtered out product

3. Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

Not using the bleach wipes therefore not using things that are toxic

4. Chemical products should be designed to preserve efficacy of function while reducing toxicity.

Does the glue still work as well if we change the process?

5. The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary whenever possible and, innocuous when used.

Do we need all of the ingredients like the beets for coloring? Could we cut some of the ingredients out and still have it work as well?

6. Energy requirements should be recognized for their environmental and economic impacts and should be minimized.  Synthetic methods should be conducted at ambient temperature and pressure.

Could we test a way to use less energy – how much is optimal? What is the least we need to heat the milk to make it curdle?

7. A raw material feedstock should be renewable rather than depleting whenever technically and economically practical.

Use a glass stirring rod or a wooden spoon instead of a plastic spoon to stir the mixture.

8. Unnecessary derivatization (blocking group protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible.

Beets are to change the properties of the glue. If we actually wanted red glue we could add something that is additive such as food coloring in order to prevent waste.

9. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

The vinegar is a catalyst. Is it strong enough to reuse once filtered from the Casein?

10. Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation products.

Glitter is plastic, a petroleum product. If the glitter is removed, the glue becomes innocuous.

11. Analytical methodologies need to be further developed to allow for real-time in-process monitoring and control prior to the formation of hazardous substances.

We cut out steps and looked for ways to make the formula simpler. We constantly monitored the heating process in order to note that maybe we could reduce the amount of vinegar used instead of waiting for it to evaporate after we make the glue.

12. Substances and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires.

Safety glasses and gloves are worn to diminish any potential for accidents. By limiting the heating steps, we are reducing the potential for accidents, explosions and fires.

**Writing the Principles: Properties of Matter (Optional Activity)**

In your lab groups evaluate the properties of the material you have just created.

Properties of matter worksheet

Color:

Melting Point:

Boiling Point:

Solubility:

Electrical Conductivity:

Toxicity:

Impact on the environment:

**Teacher Background Information**

***The 12 Principles of Green Chemistry***

1. *Pollution Prevention*

This principle is the most obvious. It goes back to the old adage “an ounce of prevention is worth a pound of cure”. It is better to prevent waste than clean it up after-the-fact. Throughout history there were many cases of environmental disasters that demonstrated this (Bhopal, India; Love Canal; Times Beach; Cuyahoga River).

1. *Atom Economy*

This principle gets more into the actual chemistry of how products are made. As chemists, atoms are assembled to make molecules. The molecules are assembled together to make materials. This principle says that it is best to use all the atoms in a process. And, those atoms that are not used end up as waste. The atom economy is a simple calculation that can be used when teaching stoichiometry and chemical reactions. The calculation is: A.E. = Formula Weight (FW) of Product divided by the FW of all of the reactants. It is a simple measure of the amount of waste in a process.

1. *Less Hazardous Chemical Synthesis*

This principle is aimed at reducing the hazard of the chemicals that are used to make a product. Throughout the history of how we have invented products and developed the process for making them, chemists have traditionally not thought about what reagents they are using and the hazards that are associated with them. Chemists have traditionally used whatever means necessary. Today we are finding that less hazardous reagents and chemicals can be used in a process to make products… and, many times they are made in a more efficient manner!

1. *Designing Safer Chemicals*

The previous principle was focused on the process. This principle focuses on the product that is made. Everyone wants safe products and efficacious. We can design safer chemical products that do what they are supposed to do, but have reduced toxicity. A good example of this is pesticides; which are products that are designed to be toxic. Many researchers are focused on created pesticides that are highly specific to the pest organism, but non-toxic to the surrounding wildlife and ecosystems.

1. *Safer Solvents and Auxiliaries*

Many chemical reactions are done in a solvent. And, traditionally organic solvents have been used that pose hazards and many are highly toxic. They also created volatile organic compounds (VOC’s) which add to pollution and can be highly hazardous to humans. This principle focuses on creating products in such a way so that they use less hazardous solvents (such as water). A good example of this is nail salons. Have you walked by them and caught a smell of the solvents that are used? The solvents that are used in salons can pose a hazard to humans. Many researchers are focused on creating products, such as nail polish, that will not have the solvents in them. For example, a completely water-based polish would avoid the exposure that goes along with the nail products and reduce the hazards associated with it.

1. *Design for Energy Efficiency*

Today there is a focus on renewable energy and energy conservation. This principle focuses on creating products in a highly efficient manner and reducing the energy associated with creating products.

1. *Use of Renewable Feedstocks*

90-95% of the products we use in our everyday lives are made from petroleum. Our society not only depends on petroleum for transportation and energy, but also for making products. This principle seeks to shift our dependence on petroleum and to make products from renewable materials that can be gathered or harvested locally. Biodiesel is one example of this where researchers are trying to find alternative fuels which can be used for transportation. Another example is alternative, bio-based plastics (plastics are made from petroleum also). PLA (polylactic acid) is one plastic that is being made from renewable feedstocks such as corn and potato waste.

1. *Reduce Derivatives*

This principle is perhaps the most abstract principle for a non-chemist. The methods that chemists use to make products are sometimes highly sophisticated. And, many involve the manipulation of molecules in order to shape the molecules into what we want them to look like. This principle aims to simplify that process and to look at natural systems in order to design products in a simplified manner.

1. *Catalysis*

In a chemical process catalysts are used in order to reduce energy requirements and to make reactions happen more efficiently (and many times quicker). Another benefit of using a catalyst is that generally small amounts are required to have an effect. And, if the catalyst is truly a “green” catalyst it will have little to no toxicity and it will be able to be used over-and-over again in the process.

1. *Design for Degradation*

Not only do we want materials and products to come from renewable resources, but we would also like them to not persist in the environment. There is no question that many products we use in our daily lives are far too persistent. This principle seeks to design products in such a way that they perform their intended function and then, when appropriate, they will degrade into safe, innocuous by-products when they are disposed of.

1. *Real-time Analysis for Pollution Prevention*

Imagine if you have never baked a cake before in your life. You mix the ingredients; you place the cake in the oven. But, for how long do you cook it and at what temperature? How will you know when the cake is done? What happens if you cook it too long or for not enough time? This process is similar to what chemists have to do when they make products. How long do they allow the reaction to run for? When do they know it will be “done”? If there was a way to see inside the reaction and to know exactly when it would be done, then this would reduce waste in the process and ensure that your product is “done” and is the right product that you intended to make.

1. *Inherently Safer Chemistry for Accident Prevention*

This principle focuses on safety for the worker. It is better to use materials and chemicals that will not explode, light on fire, ignite in air, etc. when making a product. There are many examples where safe chemicals were not used and the result was disaster. A recent example is that in Danvers, Massachusetts where a company had an explosion that resulted in many homes surrounding the plant being destroyed; luckily there were no deaths and very few injuries. But, the type of chemicals that poses these hazards should be avoided to minimize accidents.

**Analogies to use with your students:**

Here is a list of analogies that teachers and students have come up with to help put the 12 principles in a way that everyone will understand them. Please let us know if you have one to add.

**#1** It is better to put your clothes in the laundry hamper as you take them off than having them accumulate on your floor until you can’t open the door of your room and your mom yells at you.

**#8** For years, chemists have worked on trying to get molecules to do things that they want them to do and to become things that they have to force them to become. In green chemistry we take into account what the molecule is predisposed to be and how it wants to behave. It is like molecular career counseling.

**#9** Green catalysts are like bicycle stands. You need one to assemble a bicycle and then once the bicycle is made you can remove it and assemble another one. If the stand were made out of wood it would also be renewable which is the best kind of catalyst.

**#11** Real-time analyses is like when you are cooking a meal and it is something you have never tried before, you can’t just walk away from it. You have to be constantly checking to see if the food is cooked and checking to make sure it tastes right. Scientists also need to be monitoring their processes constantly to make sure that they are getting the product that they want in the way that they want and using the other principles to assess these things.

**Teacher Cheat Sheet**

1. Create no waste

2. Nothing should be left over

3. No toxicity

4. Green products have to work as well as non-green products

5. Get rid of all non-essential additives

6. Reduce energy usage

7. Use renewable materials

8. Get rid of as many steps as possible

9. Make use of a reusable method to speed up a reaction

10. Use materials that break down in the environment (Biodegradable)

11. Check everything you do against the other principles

12. Safety first

**Writing the Principles: The Lemonade Alternative**

**Student Recipe Sheet**

**Lemonade**

You will need:

* 1 cup sugar
* 1 cup water
* 10 lemons
* 1 can of coke
* 3 to 4 cups cold water
* 1 bag of ice
* Disposable cups for serving
* 1 knife
* 1 cutting board
* Hotplate
* 1 lemon squeezer
* Small saucepan
* 1 wooden spoon
* Bleach wipes

**Directions:**

1. Make sure that you have a gallon of water cooling in the refrigerator for at least 5 hours prior to making your lemonade. Open up the bag of sugar and measure one cup into the pan. Discard the rest of the sugar in a trash can.
2. Open the can of coke and set it aside. Measure one cup of the chilled water into a pitcher and then transfer the water from the pitcher into the pan.
3. Set the hot plate on medium and set the pan on the burner. Stir the mixture until it dissolves completely without burning while someone else in your group says the alphabet backwards. When the mixture is completely dissolved, set the mixture aside.
4. Place 8 of the lemons on a cutting board. Hold one up to your ear and see if you can hear the ocean. Slice the lemons in half.
5. Discard the lemon peels in the trash can. Using the juicer, squeeze the juice from the lemons.
6. Measure 1 cup of the lemon juice into a large pitcher. Discard the leftover lemon juice in the sink.
7. Add the sugar water to the pitcher as well.
8. Then add 4 cups of cold water to the pitcher.
9. Slice the remaining lemon and add the slices to the pitcher as a garnish.
10. Swing the bag of ice vigorously around your body. Add two handfuls of ice to the pitcher.
11. Clean up your cooking area with a bleach wipe. Do two jumping jacks and push-up.
12. Serve in plastic cups.