**12 Principle Match Up**

**MIDDLE SCHOOL**

**Green Chemistry**

**Background:** Please see the teacher background information at the end of this lesson for definitions, useful analogies and a deeper explanation of each principle.

**Goal:** To provide students with a basic understanding of the concept of green chemistry and the scientific terminology used in the 12 Principles of Green Chemistry.

**Objectives:** Students will …

* Identify the 12 Principles of Green Chemistry in simplified terms
* Match simplified versions to technical terminology
* Make real world applications

**Materials:**

* 12 Principles Match Up – Student Directions
* 12 Principles Match Up – Student Reinforcement Table
* 12 Principles Match Up – Teacher Information Sheet

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

**Standards Met:**

* Abilities necessary to do scientific inquiry

**Green Chemistry Principles Addressed:** 1–12 (see Student Sheet 2 for complete list)

**Procedure:**

PREP

* Cut out the squares on the 12 Principles Match Up – Student Directions
  + You may want to create one class set by laminating copies

IN CLASS

* Project the 12 Principles of Green Chemistry and ask students to explain what Principle 9 means
  + Don’t wait too long!
* Explain to students that scientists often use vocabulary that everyone else is not accustomed to hearing.
* Reinforce that it is okay if they could not understand Principle 9; most people couldn’t
* Let them know that the purpose of today’s activity is to help them decipher the chemists’ difficult language
* Students should work in pairs for this activity
* Review the glue activity, reminding students of the overarching themes
* Explain that there are 12 Principles of Green Chemistry and that today they will learn about them
* Give each pair of students a set of cards, review the directions, and give students time to complete the exercise.
  + Remind them not to yell out the answer
* ANSWER: The grass was greener there!
* Give each student a Student Reinforcement Table, review directions, and give students time to complete the exercise
  + Refer to Teacher Information Sheet for 12 Principles and Simplified explanations
* Go over each Principle, explaining where necessary.
* Ask students to share their examples from real life.
* Revisit the idea of understanding complicated language and that they can successfully decipher it

**Active Classroom Option:** Give each student a card and allow them to get up and walk around to find the appropriate partner, instead of matching at their desks.

**Assessment:**

* Completion of the Student Sheets

**12 Principle Match Up:**

**12 Principles of Green Chemistry**

|  |
| --- |
| **12 Principles** |
| 1. **Prevention.** Design chemical syntheses to prevent waste, leaving no waste to treat or clean up. |
| 2. **Atom Economy.** Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms. |
| 3. **Less Hazardous Chemical Synthesis.** Design syntheses to use and generate substances with little or no toxicity to humans and the environment. |
| 4. **Designing Safer Chemicals.** Design chemical products to be fully effective, yet have little or no toxicity. |
| 5. **Safer Solvents & Auxiliaries.** Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals. |
| 6. **Design for Energy Efficiency.** Run chemical reactions at ambient temperature and pressure whenever possible. |
| 7. **Use of Renewable Feedstocks.** Use raw materials and feedstocks that are renewable. Renewable feedstocks = farm products or the wastes of other processes; depleting feedstocks = fossil fuels (petroleum, natural gas, or coal) or are mined. |
| 8. **Reduce Derivatives.** Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste. |
| 9. **Catalysis.** Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once. |
| 10. **Design for Degradation.** Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment. |
| 11. **Real-time Analysis for Pollution Prevention.** Include in-process real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts. |
| 12. **Inherently Safer Chemistry for Accident Prevention.** Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment. |

**12 Principle Match Up - Student Directions**

* Put the blue cards in order from 1 to 12.
* Match the blue card with the corresponding yellow card, keeping the cards in order.
* Write the letters in order to discover the answer to the age old question:
  + *Why did the green chemist cross the road?*

SHHH! Don’t share the answer once you’ve discovered it.

✂ -----------------------------------------------------------------------------------------------------------------

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|  |  |  |
| --- | --- | --- |
| **Principle Part 1** |  | **Principle Part 2** |
| 1. Prevent  T | waste  H |
| 2. Use all the atoms in  E | the final product  G |
| 3. Don’t use  R | ingredients that are not essential  A |
| 4. Make safe products that  S | work as well as products that do not adhere to the 12 Principles of Green Chemistry  S |
| 5. **No**  W | toxic ingredients  A |
| 6. Reduce energy usage by  S | running experiments at room temperature  G |
| 7. Use materials that are  R | renewable. (90-95% of the products we use in our everyday lives are made from petroleum; this is non-renewable.)  E |
| 8. Let the atoms & molecules be what  E | they want to be. Don’t try to change their natural properties.  N |
| 9. Make use of a reusable method to  E | speed up a reaction  R |
| 10. Make products that will  T | break down into safe substances after we finish using them. (biodegrade)  H |
| 11. Pay attention to your chemical reaction and collect data  E | while it is happening. That way, you won’t mess it up.  R |
| 12. Safety  E | first  ! |

**12 Principle Match Up:**

**Student Reinforcement Table**

* In the center column, marked “simple version” write the simple version for each principle from the cards
* In the “example column” write a real life example that illustrates each principle. Feel free to draw a picture

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| --- | --- | --- |
| **Principle** | **Simple Version** | **Example** |
| 1. **Prevention.** Design chemical syntheses to prevent waste, leaving no waste to treat or clean up. |  |  |
| 2. **Atom Economy.** Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms. |  |  |
| 3. **Less Hazardous Chemical Synthesis.** Design syntheses to use and generate substances with little or no toxicity to humans and the environment. |  |  |
| 4. **Designing Safer Chemicals.** Design chemical products to be fully effective, yet have little or no toxicity. |  |  |
| 5. **Safer Solvents & Auxiliaries.** Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals. |  |  |
| 6. **Design for Energy Efficiency.** Run chemical reactions at ambient temperature and pressure whenever possible. |  |  |
| 7. **Use of Renewable Feedstocks.** Use raw materials and feedstocks that are renewable. Renewable feedstocks = farm products or the wastes of other processes; depleting feedstocks = fossil fuels (petroleum, natural gas, or coal) or are mined. |  |  |
| 8. **Reduce Derivatives.** Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste. |  |  |
| 9. **Catalysis.** Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once. |  |  |
| 10. **Design for Degradation.** Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment. |  |  |
| 11. **Real-time Analysis for Pollution Prevention.** Include in-process real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts. |  |  |
| 12. **Inherently Safer Chemistry for Accident Prevention.** Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment. |  |  |

**12 Principle Match Up – Teacher Information Sheet**

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| --- | --- | --- |
| **Principle** | **Simplified Form** | **Examples** |
| 1. **Prevention.** Design chemical syntheses to prevent waste, leaving no waste to treat or clean up. | Prevent waste so you don’t have to clean it up later | Only take as much food as you will eat |
| 2. **Atom Economy.** Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms. | Avoid a process that creates waste.  How are products made? Atoms are assembled together to make materials. It is best to use all the atoms in a process. Those atoms that are not used end up as waste | Making a valentine’s day card. When you cut out the heart, you can use both the heart and the heart outline left by the blank space |
| 3. **Less Hazardous Chemical Synthesis.** Design syntheses to use and generate substances with little or no toxicity to humans and the environment. | Use less hazardous reagents and chemicals in the process to make products (focus on the process, not the product) | Hair dye. The process of dying hair can be toxic and actually burn the hair. There are less toxic ways to dye hair, like lemon juice & sunshine. The final product (hopefully) looks good |
| 4. **Designing Safer Chemicals.** Design chemical products to be fully effective, yet have little or no toxicity. | This principle focuses on the product, not the process. Make safe products that work. | DDT. Pesticides can be extremely toxic. We now have more benign choices |
| 5. **Safer Solvents & Auxiliaries.** Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals. | Create products so that they use less hazardous solvents (such as water). | Imagine dissolving Kool Aid in acetone, instead of water |
| 6. **Design for Energy Efficiency.** Run chemical reactions at ambient temperature and pressure whenever possible. | Use less energy to create products. Run reactions at room temperature, don’t freeze or heat them. | Letting warm food sit on the countertop and come to room temperature before storing it in the refrigerator |
| 7. **Use of Renewable Feedstocks.** Use raw materials and feedstocks that are renewable. Renewable feedstocks = farm products or the wastes of other processes; depleting feedstocks = fossil fuels (petroleum, natural gas, or coal) or are mined. | Make products from renewable materials; things that are replaceable or can grow back. Don’t make products from fossil fuels, like gas.  (90-95% of the products we use in our everyday lives are made from petroleum.) | Start a fire. You could use gas (a petroleum product) to start it or newspaper (a renewable resource) |
| 8. **Reduce Derivatives.** Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste. | Let the atoms & molecules be what they want to be. Don’t try to change their natural properties. | Imagine you are hosting a dinner party and short a chair. You could ask a guest to perform the duties of a chair. |
| 9. **Catalysis.** Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once. | In a chemical process, catalysts make reactions happen more quickly. Just a little bit of a catalyst can be used over and over again so there is less waste. | Tennis racket that acts as a catalyst to move the ball. What if it didn’t have strings and was covered with plastic wrap. You would have to replace the racket each time. That is a stoichiometric reaction. |
| 10. **Design for Degradation.** Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment. | Stop filling the landfill. Make products that will break down into safe substances after we finish using them. | What if there was stronger toilet paper that did not break down in water? What a waste! |
| 11. **Real-time Analysis for Pollution Prevention.** Include in-process real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts. | Pay attention to your chemical reaction and collect data while it is happening. That way, you won’t mess it up. | If you made pudding without stirring it and watching the temperature, it would burn and taste terrible. |
| 12. **Inherently Safer Chemistry for Accident Prevention.** Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment. | Focus on safety for the worker. Explosions in the lab are bad. | Hand a teenager bleach and ammonia to clean the bathroom. |

**12 Principle Match Up - Teacher Background**

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

1. *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 (Bopal, 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 as 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 nailpolish, 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, these type of chemicals that poses these hazards should be avoided to minimize accidents.