**Introduction to the 12 Principles of Green Chemistry**

Background: The Twelve Principles of Green Chemistry are guidelines that chemists are increasingly using to be more environmentally friendly. As student chemists, you too will abide by the Twelve Principles. However, professional scientists often use overly-complicated language that can be difficult to interpret, and the Twelve Principles are no exception. In this activity, you will become familiar with the Twelve Principles by writing them in simpler language.

Part 1: The Untranslated Principles – Read the descriptions of the principles below.

1. **Prevention**: It is better to prevent waste than to treat or clean up waste after it is formed.
2. **Atom Economy**: Synthetic methods should be designed to maximize the incorporation of all material used in the process into the final product.
3. **Less Hazardous Chemical Syntheses**: Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. **Designing Safer Chemicals**: Chemical products should be designed to preserve efficacy of function while reducing toxicity.
5. **Safer Solvents and Auxiliaries**: The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary whenever possible and innocuous when used.
6. **Design for Energy Efficiency**: 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.
7. **Use of renewable feedstocks**: A raw material feedstock should be renewable rather than depleting whenever technically and economically practical.
8. **Reduce Derivatives**: Unnecessary derivatization (blocking group protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible.
9. **Catalysis**: Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. **Design for Degradation:** 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.
11. **Real-time analysis for Pollution Prevention**: Analytical methodologies need to be further developed to allow for real-time in-process monitoring and control prior to the formation of hazardous substances.
12. **Inherently Safer Chemistry for Accident Prevention**: 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.

Part 2: Principle Match-up – Use the untranslated principles above to help you match each pink card to a yellow card. Write the resulting complete sentences in the table below, along with a real-life example to help you remember each principle.

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| **Principle** | **Simple Version** | **Example** |
| 1. **Prevention.** |  |  |
| 2. **Atom Economy.** |  |  |
| 3. **Less Hazardous Chemical Synthesis.** |  |  |
| 4. **Designing Safer Chemicals.** |  |  |
| 5. **Safer Solvents & Auxiliaries.** |  |  |
| 6. **Design for Energy Efficiency.** |  |  |
| 7. **Use of Renewable Feedstocks.** |  |  |
| 8. **Reduce Derivatives.** |  |  |
| 9. **Catalysis.** |  |  |
| 10. **Design for Degradation.** |  |  |
| 11. **Real-time Analysis for Pollution Prevention.** |  |  |
| 12. **Inherently Safer Chemistry for Accident Prevention.** |  |  |

**Teacher Instructions and Materials**

**Instructions:**

* Distribute the 12 Principles Match-up student handout and read the background information to students.
* Instruct students to get into groups and read through the “untranslated” principles together. Once groups are done reading, they will obtain a set of 24 cards, 12 pink and 12 yellow. Their objective is to match each pink card to a yellow card to form complete sentences that simplify the 12 Principles. When their group has finished matching up the cards, they must get their work checked before moving on to the next step, which is to record the complete sentences in the table in part 2 of the student handout. Finally, they must write a real-life example that illustrates each principle.
* Review simplified principles and examples when all groups have finished.

**Common Misconceptions and Stumbling Blocks:**

* Many students will think of recycling as an example for principles 1 and/or 7. This is not the best example for either one. Some recycling methods, such as the US exporting their recycling to other countries like China, still result in waste. Also, most recycling is done on an open-loop basis, so the material being recycled - for example, plastic in a water bottle - is not being used to make more plastic water bottles.
* Students may get hung up on principles 2 and 8 because they talk about atoms and molecules. Remind those students that their example doesn’t necessarily have to do with chemistry, and that substituting the word “ingredient” may spark more thoughts.
* Students may have trouble thinking of examples for principle 9. Teacher guidance may be necessary.

**Answer Key:**

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| **Principle** | **Simple Version** | **Example (many possible answers)** |
| 1. **Prevention.** | Prevent waste. | Eat leftovers instead of throwing food away. |
| 2. **Atom Economy.** | Incorporate all the atoms into the final product. | When baking, measure out only what you need so there is no unused flour, sugar, etc. |
| 3. **Less Hazardous Chemical Synthesis.** | No toxic ingredients. | Lead should not be found in drinking water. |
| 4. **Designing Safer Chemicals.** | Make safe products that work just as well as products that do not follow the 12 Principles of Green Chemistry. | Safer peroxide bleach should work just as well as traditional chlorine bleach. |
| 5. **Safer Solvents & Auxiliaries.** | Don’t use ingredients that are not essential. | Buy unscented laundry detergent and soap. |
| 6. **Design for Energy Efficiency.** | Reduce energy usage by running experiments at room temperature. | Wash laundry in cold water. |
| 7. **Use of Renewable Feedstocks.** | Use materials that are renewable. | Breaking down old aluminum cans to make new ones. |
| 8. **Reduce Derivatives.** | Let the atoms and molecules be what they want to be. Don’t try to change their natural properties. | Don’t engage in peer pressure or bullying. |
| 9. **Catalysis.** | Use a reusable method to speed up a reaction. | When boiling water for pasta, put a lid on the pot so the heat is trapped and it boils faster. |
| 10. **Design for Degradation.** | Use materials that will break down in the environment. | Use paper straws instead of plastic ones. |
| 11. **Real-time Analysis for Pollution Prevention.** | Pay attention to your experiment and collect data as it is happening. That way you won’t mess it up. | When cooking, make sure you’re following the recipe. |
| 12. **Inherently Safer Chemistry for Accident Prevention.** | Safety first. | Don’t text and drive. |

**Materials:** Make enough copies of these cards for all groups to have one set. Cut cards out and shuffle before distributing to students.

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| **Principle Part 1** |  | **Principle Part 2** |
| **1. Prevent** | **waste** |
| **2. Incorporate all the atoms into** | **the final product** |
| **3. No** | **toxic ingredients** |
| **4. Make safe products that** | **work as well as products that do not adhere to the 12 Principles of Green Chemistry** |
| **5. Don’t use** | **Ingredients that are not essential** |
| **6. Reduce energy usage by** | **running experiments at room temperature** |
| **7. Use materials that are** | **renewable.** |
| **8. Let the atoms & molecules be what** | **they want to be. Don’t try to change their natural properties.** |
| **9. Make use of a reusable method to** | **speed up a reaction** |
| **10. Make products that will** | **break down into safe substances after we finish using them.** |
| **11. Pay attention to your chemical reaction and collect data** | **while it is happening. That way, you won’t mess it up.** |
| **12. Safety** | **first** |