E-Factor: Green Chemistry Crown
Lesson Plan

Purpose: To introduce students to the environmental impact factor (E-factor).

Objectives: Students will …

- Understand how chemists use E-factor to determine the wastefulness of a manufacturing process
- Make green chemistry crowns
- Define and calculate the E-factor of the crown making process

Supplies: (per lab group)

- 3 pre-cut sheets of cardstock (any color)
- Scissors, hole punchers and markers (for designing the crown)
- 1 bag of adhesive jewels (in 4 different colors, incl. green)
- Scale
- Calculator
- Pencil or pen
- 3 R's card

(Instructor supplies)

- Stapler
- Staples

Classroom Procedure:

This activity works best in a classroom and community setting when students work individually.

1. Staple the 3 pieces of pre-cut cardstock to make 1 long strip (slightly overlap the ends).
2. Wrap the long strip around your head and determine how much of the strip is needed to make a crown.
3. Using scissors, cut off the extra part of the strip.
4. Staple the ends of your long strip together to make the crown.
5. Using scissors, hole-punchers and markers, decorate your crown. Save all pieces of any cardstock that you cut out from your crown and set them aside in a waste pile.
6. Remove all jewels from the bag.
7. All green jewels can be placed on the crown. All non-green jewels must go into the waste pile.
8. Using the scale, measure how much your final crown weighs.
9. Measure how much your waste weighs.
10. Calculate the e-factor of the crown making process by dividing mass of waste by mass of product.
11. Discuss what your e-factor means in terms of your crown making process being wasteful or efficient.
12. From your waste pile, pull out the non-green jewels (there should be 3 other colors).
13. Separate the jewels by color into small piles.
14. Discuss one way that you can reduce waste in your crown making process.

15. Write this down on your 3 R's card next to the "reduce" line.
16. Put jewels from one pile (all of the same color) on your crown.
17. Discuss one way that you can reuse waste in your crown making process.
18. Write this down on your 3 R's card next to the "reuse" line.
19. Put jewels from one pile (all of the same color) on your crown.
20. Discuss one way that you can recycle waste in your crown making process.
21. Write this down on your 3 R's card next to the "recycle" line.
22. Put the remaining jewels (all of the same color) on your crown.
23. Discuss how your E-factor has changed with the reduced amount of waste.
24. Put the crown on your head and proudly show off your green chemistry crown!

Cleanup:
All scrap materials (adhesive jewels' paper backings and cardstock pieces) can be used in the "making glue" activity. Alternatively, adhesive paper backings can be thrown away and cardstock pieces can be recycled.

Preparation:
- You can prepare the pre-cut sheets of cardstock by cutting 8.5" x 11" sheets of cardstock into 3 equal pieces length-wise. Paper cutters are great for this preparation.
- Cardstock is used for its heavy weight (for meaningful masses of product and waste when weighed)
    - 3 pre-cut sheets of cardstock (how much each student receives) weighs 10.5 grams
    - 1 sheet of pre-cut cardstock weighs 3.5 grams
- Colored cotton balls, stickers or other crafts items may be used instead of adhesive jewels

Notes:
For more information about E-Factor: Sheldon, R. A. ChemTech, 1994, 24, (3), 38; Sheldon, R. A. Chem Ind (London), 1992, 903; Sheldon, R. A. Chem Ind. (London), 1997, 12.

This activity was inspired by the "Sho-E-Factor". Sho-E-Factor introduces the E-factor concept by having students build their own shoe rather than a crown. Shoe-E-Factor was developed by Gordon College students Parisa Hassanzadeh, Trevor Mattos and Dave Swanson as part of Dr. Irv Levy's *GOLum* (Green Organic Literacy Forum) project and Beyond Benign's Outreach Fellows program, 2009-2010.

As we further develop this activity the idea is to weave in the concept of biodegradability by having students make their own compostable crown. We will work with companies to get supplies donated such as seed paper, PLA pieces and potato based plastic. Our goal is to minimize our own impact from the activity to have an E-factor of zero as well.

E-Factor
Background Information

Green Chemistry is the science of inventing sustainable products and processes to create safe, non-toxic materials for a sustainable society. The focus of green chemistry is innovation and creativity through chemistry.

Throughout green chemistry, there are a number of ways to determine if one method of making a product is better than another. One such metric is called the E-Factor or the Environmental Impact Factor. The E-factor is the measure of the amount of a waste generated while making a product. The simple ratio of units of waste divided by units of product tells us that the lower the E-factor, the less waste is produced.

E-factor is defined as:

E-factor = mass of waste ÷ mass of product

The principles of green chemistry direct us to reduce waste rather than dealing with it afterwards. Clearly, the best scenario is one in which no waste is produced. All of the materials that go into the system are used in the final product or they are recycled. In this case, the E-factor is zero, leading to the challenge: **"The Goal Is Zero"**.

In practice, it might be difficult to measure the amount of waste generated in a direct way. We could instead measure the quantity of material put into the system and subtract the mass of material output from the system. In the simplest case, the only output from the system would be the final product. If materials (e.g. solvents or catalysts) are recycled, however, then the output of the system would also include those materials.

E-factor = (mass of inputs - mass of outputs) ÷ mass of product

<u>Introducing E-Factor to Younger Audiences at a Community Setting</u>

To clearly communicate and visualize the e-factor concept to younger audiences, the M&M E-factor activity* may be used. In this activity, imagine that a certain person only chose to eat green M&M's and disposed of the others. In that case, you might consider the input to the system to be a normal bag of M&M's and the output to be just the green ones. Use a bag of M&M's to calculate the E-factor assuming that your product is the green M&M's.

# of Non-Green M&M's (waste/byproducts)	÷	# of Green M&M's (final product)	=	E-Factor

How does your result compare to the diagrams on the next page? What suggestions do you have to improve your E-factor and reduce the waste in your bag of M&M's?

As discussed, the most common way to improve the E-factor is to recycle some of the materials that go in to the process. This example illustrates another way to improve E-factor: by finding alternative uses for the by-products. In this case, perhaps you can find a friend who will be willing to eat nongreen M&M's (try the experiment to see!). If so, then you can include the other M&M's as useful product as well. The E-factor will now be nearly zero, but not exactly zero unless you can also find an alternate use for the empty bag.

NOTE:
Due to potential food allergies, M&Ms may be substituted with skittles. However, some parents may be weary of their children eating candy so buttons may be used. Choose larger size buttons to reduce the risk of choking. Colored cotton balls are another great alternative.

E-factor	**M&M model**	**Industry segment**
0.1		Petrochemicals A chemical derived from Petroleum or natural gas Example: Solvents detergents, adhesives
1		Bulk Chemicals plastics and polymers Example: plastic bottles, grocery bags
10		
100		Fine Chemicals Chemicals used to make specific items Example: coating on laptop screens, electronics parts
250		Pharmaceuticals Example: antibiotics, blood thinners

*The M&M E-factor activity was adapted from Professor Irv Levy of Gordon College, "The goal is zero; E-factor as a green chemistry metric" http://www.cs.gordon.edu/~ijl/visualizingWaste/