Radioactive Decay – Bernard Beckerman

Purpose
This lesson will be taught during a unit on nuclear reactions and will introduce students to an application of this subject. Additionally it will teach them how computers can be used to compile massive amounts of data and how large data sets can uncover patterns when things seem random.

Overview
Students will model radioactive decay using die rolls, develop a mathematical formalism for the size of a radioactive population over time, and use Excel and PhET simulations to refine their statistics and intuitive understanding of the material.

Student Outcomes
SWBAT define half-life and determine the age of a sample given its half-life and initial size. SWBAT calculate half-life of a population of dice by modeling the decay with an exponential function. SWBAT use large sample sizes to obtain accurate statistics and more accurately define trends.

Standards Addressed
NGSS: HS-PS1-8

Time
40 minutes plus a take home activity.

Level
Honors chemistry (mostly sophomores).

Materials and Tools
- Excel or other software for plotting and curve fitting
- Dice (1 per student)
- [Worksheet](#) and [exit slip](#) are linked
- Python die rolling script: http://codepad.org/N7OOI6AL
- PhET simulation: http://phet.colorado.edu/en/simulation/radioactive-dating-game

Preparation
The take-home part of the lesson will require students to install the "Radioactive Dating Game" PhET simulation. Have them do this before class so they can come to you with questions about installation. Formally pre-assess, making sure to include the following:
- What is nuclear decay?
- Why do nuclei decay?
- What are some examples of stable and unstable nuclei?
- Look up one instance in which carbon dating was used and write two or three sentences about it.
- If you are unsure of your students' command of logarithms, this may be a good time to find out.

Prerequisites
A command of logarithms would help the mathematical portion of this lesson but is not necessary. If students are unfamiliar with logs consider modifying question 2 on the worksheet. Students should also understand the definition of an isotope and how to calculate the number of protons and neutrons in an atomic nucleus given the element and the mass, and should be familiar with common types of nuclear reactions.

Background
Every day huge numbers of particles called cosmic rays hit the outer atmosphere* and alter the nuclei of the atoms they encounter. One common example that will feature in our lesson is for a neutron to hit a nitrogen-14 atom and knock a proton loose [draw diagram, ask students which element/isotope this forms]. C-14 is not stable but decays over time. To complicate things, we can't predict exactly when a radioactive atom will decay, only it's probability over a certain time, kind of like a die roll. I can't tell you exactly what will be rolled and when, but I can tell you that on a given roll there is a 1/6 chance of rolling a 1, etc. Let's say this dice represents a C-14 atom and it decays when a 1 is rolled. We'll use this model to study how random decays like that of C-14 lead to predictable patterns in a large population, and to see how we can calculate the age of a sample using this knowledge.

*Possible elaboration: the most energetic of these are about ten million times more energetic than the stuff at CERN. There are single protons with the kinetic energy of a 100mph ping pong ball! There are competing theories as to their origin ranging from supernovae to dark matter but nobody knows for sure.

Teaching Notes
Hand out one die to each student. Instruct the students to roll until their die decays (rolls a 1) and to remember the number of rolls it took them. Ask the class "how many rolls does it take to get a 1?" Acknowledge that some students may have taken longer than others, and ask students why this may be the case. Compile and plot the live population as a function of time (in Excel if you like) by asking how many students decayed on the first roll, the second, and so on. Given a class size of 20 or more this should generate a decent exponential. This is a good opportunity to discuss the likely jagged nature of the curve. How might we get a smoother curve? The analogy of polling a population may be useful here. We can use larger sample sizes to generate smoother statistics. What if we could roll thousands of dice?

Here is where the computers come in. The Python die rolling script is designed to roll n_dice dice exactly once (n_dice can be modified at the top of the script) and outputs how many of each face value you rolled. Demonstrate it briefly for the class and the students can begin the handout.

Assessment
The pre-assessment will provide the instructor with how well students grasp the conceptual material, though an informal discussion at the end of the class session will help solidify this knowledge and tie it together with the activity. Students will be assessed based on the completed worksheet and a snapshot of the completed radioactive dating game from the PhET simulation.

In addition the attached exit slip should be given 5 minutes before the end of the session. Again the difficulty of these question number one should be modified depending on the students' understanding of logs.

Additional Information
If the spreadsheet software you are working with is not capable of curve fitting, this website (http://zunzun.com/Equation/2/UserDefinedFunction/UserDefinedFunction/) may be helpful (it is a great web resource for fitting arbitrary functions).