Nitrogen Cycling in Ecosystems

In order to have a firm understanding of how nitrogen impacts our ecosystems, it is important that students fully understand how the various forms of nitrogen cycle through the environment. The nitrogen cycle is most often introduced as a part of the biogeochemical cycles that are covered early in the year during units on ecosystem structure and dynamics. However, textbooks typically used in the AP Environmental Science course often vary with the level of depth and detail in which they cover the topic of the nitrogen cycle. The following is a summary of the foundational knowledge students should have regarding the nitrogen cycle in order to fully grasp its role in agricultural practices as well as its potential as an air and water pollutant, topics typically covered later in the course.

Nitrogen Fixation:

Nitrogen Fixation is the conversion of atmospheric nitrogen (N_2) into reactive compounds such as ammonia (NH_3) and nitrate (NO_3^-). The breaking of the bonds between the nitrogen atoms requires a great deal of energy and occurs naturally in two primary ways:

1. Abiotic Fixation: Nitrate is the result of high energy fixation in the atmosphere from lightning and cosmic radiation. In this process, N_2 is combined with oxygen to form nitrogen oxides such as NO and NO_2, which are carried to the earth's surface in rainfall as nitric acid (HNO_3). This high energy fixation accounts for approximately 10% of the nitrate entering the nitrogen cycle.

2. Biological fixation: Biological fixation is accomplished by a series of soil micro-organisms such as aerobic and anaerobic bacteria. Often, symbiotic bacteria such as *Rhizobium* are found in the roots of legumes and provide a direct source of ammonia to the plants. In root nodules of these legumes, the bacteria split molecular nitrogen into two free nitrogen atoms, which combine with hydrogen to form ammonia (NH_3). The following plants are common examples of legumes: clover, alfalfa, soy beans, and chick peas. The breakdown of these legumes by bacteria during ammonification actually returns excess nitrogen not utilized by the plant to the surrounding soil. Therefore, to promote sustainable soil fertility, it is beneficial to use these agricultural crops in rotation with other plants, such as corn, that are more profitable but deplete the available nitrogen in the soil-Some free-living aerobic bacteria, such as *Azotobacter*, and anaerobic bacteria, like *Clostridium*, freely fix nitrogen in the soil and in aquatic environments. Some members of the photosynthetic Cyanobacteria phylum fix nitrogen in aquatic environments as well.

Nitrification:

Nitrification is the process by which ammonia is oxidized to nitrite ions (NO_2^-) and then to nitrate ions (NO_3^-), which is the form most usable by plants. The two groups of micro-organisms involved in the process are *Nitrosomas* and *Nitrobacter*. *Nitrosomas* oxidize ammonia to nitrite and *Nitrobacter* oxidize nitrite to nitrate.

Assimilation:

Nitrates are the form of nitrogen most commonly assimilated by plants through root hairs. Since heterotrophic organisms cannot readily absorb nitrogen as plants do, they rely on acquiring nitrogen-based compounds through the food they eat. Since plants are the base of the food chain, the nitrogen-based compounds they have assimilated into their tissue will continue to pass from one organism to another (through consumption) as matter and energy transfers through the ecosystem's food web.

Ammonification:

In ammonification, a host of decomposing microorganisms, such as bacteria and fungi, break down nitrogenous wastes and organic matter found in animal waste and dead plants and animals and convert it to inorganic ammonia (NH_3) for absorption by plants as ammonium ions. Therefore, decomposition rates affect the level of nutrients available to primary producers.

Denitrification:

Denitrification is the process by which nitrates are reduced to gaseous nitrogen (N_2) and lost to the atmosphere. This process occurs by facultative anaerobes in anaerobic environments. Farmers with waterlogged fields and soils that have high clay content are especially vulnerable to nitrogen losses due to denitrification.

Learning Activity: Nitrogen Cycle Review Game

It is important to ensure that students have a strong knowledge of the nitrogen cycle prior to moving on to activities that address nitrogen's role in agriculture or as an air and water pollutant. One method of reviewing the nitrogen cycle with students is to have them participate in an activity where they take on the role of nitrogen atoms moving through the nitrogen cycle. This reinforces the numerous pathways in the cycle and its importance to living organisms. The instructions and board game set-up provided here are simply one template for this activity. Teachers may choose to have the students design the board game themselves, whereby they would need to identify and describe the parts of the nitrogen cycle that are appropriate and should be included in the game.

Instructions for the Nitrogen Cycle Game:

1. Groups should have three students, if possible. Each student chooses a playing piece (from old board games, buttons, or a coin marked with tape); this playing piece represents a nitrogen atom. Each group needs two coins and a playing board. Each student requires a rules sheet (see Appendix A) and a copy of the playing board (see Appendix B). The group will need colored pencils as well.
2. Tell the students to begin by placing pieces on space #1. At the start of a turn, students should flip the coins as instructed in Appendix A, following the instructions as they go. Make sure students do not simply follow the sequence of numbers but instead follow the chance moves that the coins present. Two or more players can occupy the same place. Remind students that when or if their nitrogen atom is returned to the atmosphere, they have completed one cycle. Students should continue to play until you direct them to stop.
3. On the individual game board, students should use the colored pencils to keep track of their different cycles, with each color representing a single cycle. They should label the cycles "1st, 2nd," etc. Everyone who travels through the cycle and understands their process is a winner … BUT, for "fun," ask students:
   a. Who visited the most organisms?
   b. Who completed the most cycles?
   c. Who completed the longest cycle? The shortest?
   d. Who spends the most time in the atmosphere?
4. Have fun … then ask students to answer the following questions on a separate sheet of paper or in their lab book. These questions can be used as a formative assessment to help teachers determine whether or not the students have sufficient knowledge of the nitrogen cycle to move on to the next activities, which focus more on nitrogen's role in agriculture and as a pollutant in ecosystems.

Post-Activity Discussion/Questions for Review Game:

The background and review game focuses on the foundational knowledge that students would be expected to gain during an introductory unit on the biogeochemical cycles in ecosystems. Therefore, for the sake of time and space, some important pathways have been left out of the game. Depending on when this activity is being utilized in the AP Environmental Science course, students may be able to discuss other sources for nitrogen entering and cycling through ecosystems. In particular, students should eventually be able to describe in detail how the addition of fertilizer and the burning of fossil fuels would impact the nitrogen cycle.

1. In the course of the nitrogen cycle, are nitrogen atoms themselves ever created? Ever destroyed? Ever changed into other kinds of atoms? Ever changed into other compounds? Explain why or why not.
2. Discuss what moves on the game board represented the following processes of the nitrogen cycle: Nitrogen Fixation, Nitrification, Ammonification, Assimilation, Denitrification.

Appendix A: The Nitrogen Cycle Game

NOTE: H=Heads T=Tails (for example TH = one heads & one tails for that turn)
To Begin: *Start at Number 1. For each turn you will need to flip both coins.*

1. Your NITROGEN ATOM is now a Molecule of N_2 in the Atmosphere.
Flip the two coins

TT	Not absorbed; your nitrogen atom remains in the atmosphere. *Flip again.*
HT or TH	The nitrogen atom is oxidized by lightning to form NO or NO_2 which combines with rain to produce nitric acid (HNO_3). *Go to number 6.*
HH	Your nitrogen atom has now been deposited in air pockets in the soil. *Go to number 3*

2. Your NITROGEN ATOM has now been ASSIMILATED into a Plant Leaf as a component of an Organic Molecule.
Flip the two coins

TT or HH	The plant leaf is eaten by an animal. *Go to number 8.*
TH or HT	The plant dies and falls to the ground. It starts to decompose and its organic matter helps form detritus that will become part of the humus. *Go to number 7.*

3. Your NITROGEN ATOM is in the SOIL (as N_2)
Flip the two coins

TT	Your nitrogen atom is not fixed by bacteria and returns to the atmosphere. *Return to number 1.*
TH or HT	Your nitrogen atom is converted to nitrite. *Go to number 4.*
HH	Your nitrogen atom is fixed by nitrogen-fixing bacteria and is now part of ammonia (ammonium ions, NH_4^+). *Go to number 9.*

4. Your NITROGEN ATOM is in the SOIL (as NO_2^-)
Flip the two coins

TT or HH	Your nitrogen atom is not converted by the nitrifying bacteria. *Skip a turn.*
TH or HT	Your nitrogen atom is converted to nitrate (NO_3^-) by nitrifying bacteria. *Go to number 5.*

5. Your NITROGEN ATOM is in the SOIL (as NO_3-)

Flip the two coins

TT	Your nitrogen atom has been released to the atmosphere as N_2 by denitrifying bacteria. *Return to number 1.*
TH, HT, or HH	Your nitrogen atom is now absorbed by a plant through water intake (as nitrate). *Go to number 2.*

6. Your NITROGEN ATOM is now a part of NITRIC ACID (HNO_3).

Flip the two coins

HH	The nitrogen readily releases hydrogen and forms nitrite (NO_2^-). Go to *number 4.*
TH, HT, or TT	The nitric acid readily releases hydrogen and forms nitrate (NO_3^-). *Go to number 5.*

7. Your NITROGEN ATOM is now in a part of DETRITUS (dead organic matter)

Flip the two coins

HT or TH	Your nitrogen atom has been converted by a decomposer into ammonia (ammonium ions) that has been absorbed by a plant. *Go to number 2.*
HH or TT	Your nitrogen atom has been converted into ammonia (ammonium ions) that remains in the soil. *Go to number 9.*

8. Your NITROGEN ATOM is now in a MOLECULE of TISSUE in a CONSUMER

Flip the two coins

HT or TH	Your nitrogen atom remains in the tissue of the consumer. *Skip a turn.*
HH or TT	When the consumer dies of injury and/or disease the nitrogen atom will eventually helps form detritus material. *Go to number 7.*

9. Your NITROGEN ATOM is now AMMONIA (ammonium ion) present in the soil.

Flip the two coins

TT or HH	The molecule with your nitrogen remains in the soil as ammonia. *Skip a turn.*
TH or HT	The nitrogen atom is released to the atmosphere as N_2 by denitrifying bacteria. *Return to number 1.*

Appendix B: NITROGEN CYCLE GAME BOARD