Laboratory 1
Evolution by Means of Natural Selection

(FOR TODAY'S LAB, WEAR CLOTHING THAT WILL ALLOW YOU TO ROOT AROUND IN THE GRASS. NO HIGH HEELS, SHORT DRESSES, ETC. DRESS AS IF YOU WERE GOING TO BE A FIELD BIOLOGIST FOR A DAY.)

Organic evolution, biological change over time in living organisms, is an observable phenomenon, not a theory. Tremendous amounts of scientific data support the fact that evolution of natural populations has occurred in the past, and is still occurring now.

The only thing theoretical about evolution is not *that* it occurs, but *how* it occurs. Five main phenomena can contribute to a population's evolution, including

1. **mutation** – changes in the genes of the population are the raw material of evolution.
2. **migration** - immigration of individuals into or emigration of individuals out of a population can change the genetic composition of that population.
3. **non-random mating** – if certain individuals in a population mate together more or less frequently than predicted by random chance, this can change the genetic composition of the population. (assortative mating)
4. **small population size** – if a small, genetically non-representative sample of a large population is isolated from that large population, the small population's genetic composition will change, relative to that of the large population (genetic drift).
5. **natural selection** – this will take a little more explanation. Fasten your lab belts.

Natural Selection

In his work, *On the Origin of Species by means of Natural Selection*, Charles Darwin presented one of the most important ideas in modern biology, that evolution proceeds by means of **natural selection**. His ideas can be distilled into four main tenets:

1. **Overproduction**: Members of a species have the capacity to produce large numbers of offspring. Within each generation, more offspring are produced than can be supported by limited environmental resources.
2. **Variation**: Members of the same species exhibit variable phenotypic traits, and some of this variation is heritable.
3. **Competition**: Members of the same species must compete for limited environmental resources.
4. **Differential Reproduction**: Survival and reproduction are not random: the members of a species whose heritable traits enable them to best exploit environmental resources should leave more offspring (and a higher proportion of their genes) than those whose heritable traits are less favorable a particular environment. The former are said to be ***naturally selected***.

The results of natural selection are everywhere around you. The warning (= **aposematic**) coloration of a stinging bee, the shape of a woodpecker's bill, perfect for extracting insects from rotting wood, the camouflaging (= **cryptic**) coloration of a lizard against tree bark all have resulted from natural selection.

Mutations--changes in DNA—from one generation to the next provide the raw material for evolution. In a nutshell, any mutation may categorized as:

- **adaptive** – increases the chances of reproduction in the individual carrying it
- **maladaptive** – decreases the chances of reproduction in the individual carrying it
- **neutral** – does not effect the chances of reproduction in the individual carrying it

The ancestors of today's living organisms carried adaptive mutations that might have made them slightly better equipped for survival in a changing environment than other members of their species (their **conspecifics**) who lacked those mutations. Individuals best able exploit the environment (e.g., efficient at finding food, resistant to pathogens, etc.) and out-compete their conspecifics were more likely to survive and leave the most offspring to the next generation. Whoever has the most babies--wins!

Microevolution vs. Macroevolution

A **species** may be defined as a group of similar organisms within which there is gene flow (i.e., which can interbreed in nature to produce fertile, viable offspring). Members of different species are **reproductively isolated** from each other: they cannot breed together to produce fertile, viable offspring. This reproductive isolation may be a result of various mechanisms, some of which prevent zygote formation (**prezygotic** isolating mechanisms) and others preventing hybrid offspring from surviving or reproducing (**postzygotic** isolating mechanisms).

A **population** is all individuals of a single species living within a defined area. The area's boundaries may be geographic, or they may be defined arbitrarily by the investigator studying the population. A **community** is all the populations of living organisms living within a defined area, and the **ecosystem** is defined by the interactions of the living communities with one another and with the inorganic environment, including water, air, climate, seasons and the earth itself.

Evolution can proceed gradually, consisting of genetic changes within a population without the generation of new species (**microevolution**). Eventually, if some members of a population change to the degree that they are able to interbreed only with each other, and no longer with the other members of their original population, **speciation** (**macroevolution**) has occurred.

True speciation may take millennia, but we can observe microevolutionary changes in populations via natural selection with a simple exercise. We will examine the results of interaction between prey species (*Beanus spp.*) and a predator species (modified *Homo sapiens*, played by you). In real life, natural selection isn't much fun if you're the loser. But today's demonstration should be fun, even if some of us will "go extinct." You and your colleagues will become predators each with a different type of mouthpart. Your prey will be four different types of beans of various colors and sizes. Natural selection, often a double-edged sword, will act on both predator and prey. In this experiment you will consider

1. the effectiveness of the prey item's morphology (color and shape) at preventing it from being detected and captured by the predator
2. the effectiveness of the predator's feeding apparatus at allowing it to forage for enough prey to survive and leave offspring
3. Other factors that might affect survival and reproduction in either predator or prey.

Our experimental system today includes four species of prey, and five species of predators (a total of ten populations in this community and ecosystem). The prey species are closely related, but reproductively isolated from one another. They are:

Beanus melanus	(Black Bean)
Beanus albus	(White Bean)
Beanus maculatus	(Pinto Bean)
Beanus rubrus	(Red Bean)

The five different predator species (to be played by YOU) are:

Fabanthropus meniscostoma	(Spoon-Mouthed Bean-eating Ape)
Fabanthropus forficatostoma	(Fork-Mouthed Bean-eating Ape)
Fabanthropus planistoma	(Knife-Mouthed Bean-eating Ape)
Fabanthropus acutistoma	(Chopstick-Mouthed Bean-eating Ape)
Fabanthropus amphistoma	(Tong-Mouthed Bean-eating Ape)

In today's lab, you will perform an exercise to test ideas about evolution by means of natural selection. Note that every student must collect all data for each predator and prey type. You will analyze the data and be responsible for submitting a mini-report on the results of your exercise. Your lab instructor will tell you when this is due.

Natural Selection: Bean Camouflage vs. Predator Mouthparts

Many predators rely on visual cues to detect prey. Tasty prey items that are less conspicuous than equally tasty members of their population may have a **selective advantage** over their more visible conspecifics.

Your TA will scatter an initial population of 600 *Beanus*, consisting of equal numbers of four species: 150 black (*Beanus melanus*), 150 white (*Beanus albus*), 150 pinto (*Beanus maculatus*), and 150 red (*Beanus rubrus*). The object of our hunt: to find out whether any of the four species has a selective advantage over the others, when it comes to avoiding being eaten.

You will play the part of the predators. All students in the lab will be divided into equal numbers of predators for the first generation. Each will be assigned one of five different kinds of specialized feeding structures: a color-coded cup paired with either (1) spoon (*Fabanthropus meniscostoma*), (2) fork (*Fabanthropus forficatostoma*), (3) knife (*Fabanthropus planistoma*), (4) chopsticks (*Fabanthropus acutistoma*), or (5) tongs (*Fabanthropus amphistoma)*. Are any of these predators poulations better suited than the others for capturing beans?

Hypotheses and Predictions

Before you begin any scientific venture, it is wise to have an educated idea about what you expect to observe. Consider the system described above. What is your hypothesis? (In this case, null and alternative hypotheses may be most appropriate.)

For the prey species:

What is your null hypothesis?____

____

____

What is your alternative hypothesis?____________________________________

____

____

What is your prediction? ____

____

____

For the predator species:
What is your null hypothesis? ____

____

____

What is your alternative hypothesis? ____

____

____

What is your prediction? ____

____

____

If you don't recall how to devise hypotheses and predictions, be sure to read Appendix I, linked to the lab manual web site.

READ DIRECTIONS CAREFULLY BEFORE BEGINNING!

1. Dividing the labor among the class members, count out 150 individuals of each of the available bean species.
2. Place all beans together in the container your TA provides and shake well to mix thoroughly.
3. Predators, arm yourselves! *There MUST be equal numbers of predators equipped with each of the five types of feeding structures for the first round.*
4. Your TA will scatter beans in a pre-determined area on the lawn while predators look away (no peeking!). On the timer's mark, the predators begin foraging.
5. Predators will have 90 seconds to capture as many beans as possible and place them in their mouths (color-coded cups).
6. At the end of the 90 seconds, predators of each species will band together and count the number of each species of bean they have captured.
7. When all predator teams are finished counting, one person from each predator group will call out their results. The TA will write these on the board, and EVERYONE should copy the results in Table 1-1.

PREDATOR RULES:

1. Predators must pick up prey with their feeding apparatus only. No helping with fingers or other objects, including the cups!

2. Predators may not remove prey from a fellow predator's cup (eeyuck!), but they may feel free to dash in and fight for any prey being pursued by another predator. It's a jungle out there. Hungry predators are not kind to strangers.

Ready? On your mark. Get set. GO!

After Round One of bloody carnage is over, all groups return to the lab to count and digest their prey. Use Table 1-1 below to record data from the first round of predation.

Table 1-1: Number of beans caught (by color) by each predator.

predator	black	white	pinto	red	TOTAL
spoon					
tongs					
fork					
chopsticks					
knife					
kills					
survivors					
Add to next round:					

Step One: How many beans have survived to reproduce?

Each predator type should congregate after Round One and count the number of beans of each color captured by their group. As the TA calls each group in turn (Fork! Knife! Whatever!), everyone should listen quietly as the team reports how many of each color bean their predator type captured. These data should be recorded (by everyone) in Table 1-1.

1. Enter the total number of *each color bean* killed by *each predator*, in Table 1-1.
2. To determine the number of survivors of each bean color, subtract the number killed from 150 (your original bean population). Enter these data in the bottom row.
3. For each bean color, **calculate the number of new beans to add to the population** with this formula (also shown in Table 1-2).

$$\frac{\text{\# of species X survivors}}{\text{total \# of survivors (all species)}} \times \text{total \# of beans killed (all species)} = \text{\# of new species X beans added to the population ("recruits")}$$

The answer tells us how many beans of a given species survived to have babies. Whoever has the most babies *wins* the game of natural selection.

Once the numbers of new baby beans of each species have been calculated, volunteers should count out the correct number of new recruits (born to the surviving beans of each species), then toss them into to the Bean Bin held by your TA.

ALTHOUGH THE PROPORTION OF BEANS COLORS WILL CHANGE AS PREDATION CHANGES THE COMPOSITION OF THE PREY POPULATION, THE TOTAL NUMBER OF BEANS SHOULD REMAIN THE SAME AT 600. If your calculations don't result in a total of 600 beans in the wild population, then something has gone wrong with your calculations. Go back and do it again!

BECAUSE EACH COLOR HAS DIFFERENT MORTALITY AND SURVIVORSHIP, ONLY THE *RELATIVE* NUMBERS OF EACH BEAN COLOR WILL CHANGE.

Table 1-2. *Beanus* recruitment after Round One.

a. Black Beans:

$$\frac{\text{\# of black survivors}}{\text{total \# of survivors (all colors)}} \times \text{total \# of beans killed (all colors)} = \text{\#of new black beans added to the population ("recruits")}$$

Perform your calculation for the **black** beans here:

$$\frac{(\qquad\qquad)}{(\qquad\qquad)} \times (\qquad) = \underline{\qquad\qquad\qquad} \text{ ("recruits")}$$

b. White Beans:

$$\frac{\text{\# of white survivors}}{\text{total \# of survivors (all colors)}} \times \text{total \# of beans killed (all colors)} = \text{\#of new white beans added to the population ("recruits")}$$

Perform your calculation for the **white** beans here:

$$\frac{(\qquad\qquad)}{(\qquad\qquad)} \times (\qquad) = \underline{\qquad\qquad\qquad} \text{ ("recruits")}$$

c. Pinto Beans:

$$\frac{\text{\# of pinto survivors}}{\text{total \# of survivors (all colors)}} \times \text{total \# of beans killed (all colors)} = \text{\#of new pinto beans added to the population ("recruits")}$$

Perform your calculation for the **pinto** beans here:

$$\frac{(\qquad\qquad)}{(\qquad\qquad)} \times (\qquad) = \underline{\qquad\qquad\qquad} \text{ ("recruits")}$$

d. Red Beans:

$$\frac{\text{\# of red survivors}}{\text{total \# of survivors (all colors)}} \times \text{total \# of beans killed (all colors)} = \text{\#of new red beans added to the population ("recruits")}$$

Perform your calculation for the **red** beans here:

$$\frac{(\qquad\qquad)}{(\qquad\qquad)} \times (\qquad) = \underline{\qquad\qquad\qquad} \text{ ("recruits")}$$

Step Two: How many predators have survived to reproduce?

Predators, too, have experienced differential success, and that means differential reproduction. (The more food you get, the more babies you can have.) As you will see, some feeding structures are better suited for capturing beans than others.

1. Predator groups should band together again and count the total number of beans (***all species***) killed by their species of predator. (Use the data you entered in Table 1-1 for this calculation.)
2. The total number of ALL SPECIES of beans killed by ALL PREDATORS should be entered in the last column of Table 1-1 (Total kills).
3. You can now calculate how many predators of each type will survive in the next generation with this formula (which also appears in Table 1-3):

$$\frac{\text{\# of beans killed by Predator X}}{\text{total \# of beans killed (all species)}} \times \text{total \# of predators} = \text{\#of } \textbf{Predator X}\text{, second generation}$$

4. When you have completed your calculations, report your results to your TA, who will enter them into the table on the blackboard (or projection screen).

Once each predator group has finished its calculations, establish your new predator populations. Listen carefully and quietly as your TA does the following:

1. The TA will call out each predator type. (Start with the species that decreased, and work your way up.) If the number of predators of a given type is less than the initial number in Round One, then the appropriate number of that predator type must turn in their mouthparts and cups. They have not survived the ordeal. (Don't worry. They'll be reincarnated as another predator soon. Weep not for chopsticks.)
2. The TA will repeat the process for each type of predator mouthpart.
3. If you're a predator who died in Round One, then you will be reincarnated as a different species of (more successful predator) in Round Two. For example, if chopsticks (initial population = 5) decrease by 2, and spoons increase by 2 in the next generation, then two students who played chopsticks in Round One will take up spoons in Round Two. It doesn't matter which team you're on. The important measure is the number of predators in each round.
4. When all predator populations have been reorganized for the second generation, you're ready for Round Two. Follow your TA to the hunting grounds, and go for another round of merciless bean slaughter.

Table 1-3. Predator survival in Round One and recruitment for Round Two.

a. Spoons:

<u># of beans killed by spoons</u> x total # of predators = #of **spoons**, 2nd generation
total # of beans killed (all types)

<u>Do your calculation for the **spoons** here:</u>

<u>(   )</u> x (   ) = ____________________
(   ) (# of spoons in next round)

b. Forks:

<u># of beans killed by tongs</u> x total # of predators = #of **tongs**, 2nd generation
total # of beans killed (all types)

<u>Do your calculation for the **tongs** here:</u>

<u>(   )</u> x (   ) = ____________________
(   ) (# of tongs in next round)

c. Knives:

<u># of beans killed by forks</u> x total # of predators = #of **forks**, 2nd generation
total # of beans killed (all types)

<u>Do your calculation for the **forks** here:</u>

<u>(   )</u> x (   ) = ____________________
(   ) (# of forks in next round)

d. chopsticks:

<u># of beans killed by chopsticks</u> x total # predators = #of **chopsticks**. 2nd generation
total # of beans killed (all types)

<u>Do your calculation for the **chopsticks** here:</u>

<u>(   )</u> x (   ) = ____________________
(   ) (# of chopsticks in next round)

e. knives:

<u># of beans killed by knives</u> x total # of predators = #of **knives,** 2nd generation
total # of beans killed (all types)

<u>Do your calculation for the **knives** here:</u>

<u>(   )</u> x (   ) = ____________________
(   ) (# of knives in next round)

Round Two, and Beyond

After you have calculated the next generation of predators and prey:

1. Count out the number of new bean **recruits** to be added to the existing population.
2. Add them to the "Initial Population" bin for distribution into the habitat by your TA.
3. Your TA will scatter prey on the lawn in the same habitat you hunted before, and the predators will once again set upon them for 90 seconds.
4. Repeat the calculations for predators and prey as above for Round Two, and go through at least five rounds (generations) to get a good sample over time.

Use the tables at the end of this section to enter your raw data and keep track of your calculations.

IMPORTANT HINTS

1. Once you calculate the number of **new recruits** to the population, DO NOT FORGET TO ADD THAT NUMBER TO THE SURVIVORS OF THE PREVIOUS GENERATION before you do your calculations for the next round. Unless you do this important step, your calculations will not be correct!
2. The proportions of prey species should change (if you've done your calculations correctly), but the total population should remain at 600 beans. If this is not the case (with the exception of rounding errors), then the calculations are not correct, and you need to re-do them.
3. Similarly, the total number of predators in each round should stay the same as the initial round. Only the relative frequencies of each predator species should change.

Data Analysis

Once you have completed five generations of predation, plot the results of predator and prey population changes on a graph. We'll let you decide whether to use a polygon or a histogram, but one is more appropriate than the other for these data. If you're not sure which to use, discuss this with your TA and your team.

What do the graphs tell you about the predators and prey, and their relative fitness?

Quantifying Evolutionary Fitness of competing species: W and s

The relative fitness of competing species (or competing genotypes in a single species) can be quantified by calculating the fitness and selection coefficients. The **fitness coefficient (W)** is the adaptive value of a particular species' phenotype (and genotype, if the phenotype is genetically controlled).

By definition, the species that produces the most offspring among a competing group of species is said to have a fitness of 1.0 (100%). All other competing species' W are measured relative to the most successful genotype's W.

For example, if the spoons produced 3 offspring in a given generation, the forks produced 2, and the knives produced 1, then...

Spoons:	W = 1.0	
Forks:	W = 2/3 = 0.66	(The forks are 66% as fit as the spoons.)
Knives:	W = 1/3 = 0.33	(The knives are 66% as fit as the spoons.)

Conversely, the **selection coefficient (s)** is a measure of selective pressure *against* a particular phenotype, relative to the others in the population. It is calculated as 1 - W. In our example, for each of our species:

Spoons: s = 1 - 1 = 0 (Selection against spoons, relative to others, is zero.)
Forks: s = 1 - 0.66 = 0.33
Knives: s = 1 - 0.33 = 0.66
Selection pressure is highest against the knives, relative to the others.

Armed with this information, you should be able to calculate W and s for any species of predator or prey and use this information in your written report. Use the data sheets on the following pages to record and calculate your results. You must include this information in your report.

Lab Report

In writing your report, use the standard format for a scientific paper. If you are not yet familiar with this format, read Appendix 3, linked to the main Lab Manual web site. The experiment you and your colleagues have just performed provide a quick demonstration of how interactions between two species can generate real changes in the species/genetic composition of an ecosystem.

In your introduction, provide a reasonable, logical background for the purpose of this experiment. (Don't say that it is to teach you something. Make it clear to your reader that you are performing an experiment, have an educated guess (hypothesis) about your results, and have made reasonable predictions based on logical assumptions.) Give real-life examples of predator/prey interactions that can change the composition of each population.

Describe your methods clearly, so that a reader could repeat your experiment. In the results section DO NOT merely turn in raw data sheets! Perform your calculations, and present your data in clear tables or graphs, each with an appropriate title and legend.

Finally, give a logical, well-reasoned explanation for your results in the discussion section of your paper. Consider all possible explanations for the observations. Each of these explanations should be phrased as its own hypothesis, which may or may not exclude the other hypotheses. For each explanation/hypothesis, make a prediction and suggest a possible experiment for testing that hypothesis. A scientific exploration like the one you do in lab today is only the beginning of discovery, and a good scientist maps the road beyond the day's results.

Table 1-5. Raw data - Round Two (Generation 2):

predator	black	white	pinto	red	TOTAL
spoon					
fork					
knife					
chopsticks					
tongs					
total kills					
survivors					
New recruits					
# in Generation 3					

Table 1-6. Raw data - Round Three (Generation 3):

predator	black	white	pinto	red	TOTAL
spoon					
fork					
knife					
chopsticks					
tongs					
total kills					
survivors					
New recruits					
# in Generation 4					

Table 1-7. Raw data - Round Four (Generation 4):

predator	black	white	pinto	red	TOTAL
spoon					
fork					
knife					
chopsticks					
tongs					
total kills					
survivors					
New recruits					
# in Generation 5					

Table 1-8. Raw data - Round Five (Generation 5):

predator	black	white	pinto	red	TOTAL
spoon					
fork					
knife					
chopsticks					
tongs					
total kills					
survivors					
New recruits					
# in Generation 6					

total kills = the sum of the numbers in the vertical column (bean color).
survivors = the number of beans still left in the grass at the end of the hunting period. (To calculate this, subtract the total kill of one color from initial number of that color).

Predator and Prey Reconstitution Data Sheets

Generation 1 (original starting population)

prey generation	black	white	pinto	red	TOTAL
I: total	150	150	150	150	600

Generation 2:

prey generation	black	white	pinto	red	TOTAL
a: # of kills					
b. # of survivors					
c. # of recruits					
TOTAL # IN NEXT GENERATION (add b and c)					600

Generation 3:

prey generation	black	white	pinto	red	TOTAL
a: # of kills					
b. # of survivors					
c. # of recruits					
TOTAL # IN NEXT GENERATION (add b and c)					600

Generation 4:

prey generation	black	white	pinto	red	TOTAL
a. # of kills					
b. # of survivors					
c. # of recruits					
TOTAL # IN NEXT GENERATION (add b and c)					600

Generation 5:

prey generation	black	white	pinto	red	TOTAL
a. # of kills					
b. # of survivors					
c. # of recruits					
TOTAL # IN NEXT GENERATION (add b and c)					600

Prey Population: Generation Two

a. black beans: # of black survivors / total # of survivors x total # of beans killed (all colors) = #of new black bean recruits

Do your calculation for the **black** beans here:

( ) / ( ) x ( ) = ______________ ("recruits")

b. white beans: : # of white survivors / total # of survivors x total # of beans killed (all colors) = #of new white bean recruits

Do your calculation for the **white** beans here:

( ) / ( ) x ( ) = ______________ ("recruits")

c. pinto beans: # of pinto survivors / total # of survivors x total # of beans killed (all colors) = #of new pinto bean recruits

Do your calculation for the **pinto** beans here:

( ) / ( ) x ( ) = ______________ ("recruits")

d. red beans: # of red survivors / total # of survivors x total # of beans killed (all colors) = #of new red bean recruits

Do your calculation for the **red** beans here:

( ) / ( ) x ( ) = ______________ ("recruits")

Predator Population: Generation Two

a. spoons: # of beans killed by spoons / total # of beans killed x total # of predators (all types) = #of spoons in the next generation

Do your calculation for the **spoons** here:

( ) / ( ) x ( ) = ______________ (# of spoons for next round)

b. tongs: # of beans killed by tongs / total # of beans killed x total # of predators (all types) = #of tongs in the next generation

Do your calculation for the **tongs** here:

( ) / ( ) x ( ) = ______________ (# of tongs for next round)

c. forks: # of beans killed by forks / total # of beans killed x total # of predators (all types) = #of forks in the next generation

Do your calculation for the **forks** here:

( ) / ( ) x ( ) = ______________ (# of forks for next round)

d. chopsticks: # of beans killed by chopsticks / total # of beans killed x total # of predators (all types) = #of chopsticks in the next generation

Do your calculation for the **chopsticks** here:

( ) / ( ) x ( ) = ______________ (# of chopsticks for next round)

e. knives: # of beans killed by knives / total # of beans killed x total # of predators (all types) = #of knives in the next generation

Do your calculation for the **knives** here:

( ) / ( ) x ( ) = ______________ (# of knives for next round)

Prey Population: Generation Three

a. black beans: # of black survivors / total # of survivors x total # of beans killed (all colors) = #of new black bean recruits

Do your calculation for the **black** beans here:

( ) / ( ) x ( ) = ______ ("recruits")

b. white beans: : # of white survivors / total # of survivors x total # of beans killed (all colors) = #of new white bean recruits

Do your calculation for the **white** beans here:

( ) / ( ) x ( ) = ______ ("recruits")

c. pinto beans: # of pinto survivors / total # of survivors x total # of beans killed (all colors) = #of new pinto bean recruits

Do your calculation for the **pinto** beans here:

( ) / ( ) x ( ) = ______ ("recruits")

d. red beans: # of red survivors / total # of survivors x total # of beans killed (all colors) = #of new red bean recruits

Do your calculation for the **red** beans here:

( ) / ( ) x ( ) = ______ ("recruits")

Predator Population: Generation Three

a. spoons: # of beans killed by spoons / total # of beans killed x total # of predators (all types) = #of spoons in the next generation

Do your calculation for the **spoons** here:

( ) / ( ) x ( ) = ______ (# of spoons for next round)

b. tongs: # of beans killed by tongs / total # of beans killed x total # of predators (all types) = #of tongs in the next generation

Do your calculation for the **tongs** here:

( ) / ( ) x ( ) = ______ (# of tongs for next round)

c. forks: # of beans killed by forks / total # of beans killed x total # of predators (all types) = #of forks in the next generation

Do your calculation for the **forks** here:

( ) / ( ) x ( ) = ______ (# of forks for next round)

d. chopsticks: # of beans killed by chopsticks / total # of beans killed x total # of predators (all types) = #of chopsticks in the next generation

Do your calculation for the **chopsticks** here:

( ) / ( ) x ( ) = ______ (# of chopsticks for next round)

e. knives: # of beans killed by knives / total # of beans killed x total # of predators (all types) = #of knives in the next generation

Do your calculation for the **knives** here:

( ) / ( ) x ( ) = ______ (# of knives for next round)

Prey Population: Generation Four

a. black beans: $\frac{\text{\# of black survivors}}{\text{total \# of survivors}}$ x total # of beans killed (all colors) = #of new black bean recruits

Do your calculation for the **black** beans here:

(______) x ( ) = ______
( ) ("recruits")

b. white beans: : $\frac{\text{\# of white survivors}}{\text{total \# of survivors}}$ x total # of beans killed (all colors) = #of new white bean recruits

Do your calculation for the **white** beans here:

(______) x ( ) = ______
( ) ("recruits")

c. pinto beans: $\frac{\text{\# of pinto survivors}}{\text{total \# of survivors}}$ x total # of beans killed (all colors) = #of new pinto bean recruits

Do your calculation for the **pinto** beans here:

(______) x ( ) = ______
( ) ("recruits")

d. red beans: $\frac{\text{\# of red survivors}}{\text{total \# of survivors}}$ x total # of beans killed (all colors) = #of new red bean recruits

Do your calculation for the **red** beans here:

(______) x ( ) = ______
( ) ("recruits")

Predator Population: Generation Four

a. spoons: $\frac{\text{\# of beans killed by spoons}}{\text{total \# of beans killed}}$ x total # of predators (all types) = #of spoons in the next generation

Do your calculation for the **spoons** here:

(______) x ( ) = ______
( ) (# of spoons for next round)

b. tongs: $\frac{\text{\# of beans killed by tongs}}{\text{total \# of beans killed}}$ x total # of predators (all types) = #of tongs in the next generation

Do your calculation for the **tongs** here:

(______) x ( ) = ______
( ) (# of tongs for next round)

c. forks: $\frac{\text{\# of beans killed by forks}}{\text{total \# of beans killed}}$ x total # of predators (all types) = #of forks in the next generation

Do your calculation for the **forks** here:

(______) x ( ) = ______
( ) (# of forks for next round)

d. chopsticks: $\frac{\text{\# of beans killed by chopsticks}}{\text{total \# of beans killed}}$ x total # of predators (all types) = #of chopsticks in the next generation

Do your calculation for the **chopsticks** here:

(______) x ( ) = ______
( ) (# of chopsticks for next round)

e. knives: $\frac{\text{\# of beans killed by knives}}{\text{total \# of beans killed}}$ x total # of predators (all types) = #of knives in the next generation

Do your calculation for the **knives** here:

(______) x ( ) = ______
( ) (# of knives for next round)

Prey Population: Generation Five

a. black beans: # of black survivors x total # of beans killed = #of new black bean recruits
total # of survivors (all colors)
Do your calculation for the **black** beans here:
( ) x ( ) = ______________
( ) ("recruits")

b. white beans: : # of white survivors x total # of beans killed = #of new white bean recruits
total # of survivors (all colors)
Do your calculation for the **white** beans here:
( ) x ( ) = ______________
( ) ("recruits")

c. pinto beans: # of pinto survivors x total # of beans killed = #of new pinto bean recruits
total # of survivors (all colors)
Do your calculation for the **pinto** beans here:
( ) x ( ) = ______________
( ) ("recruits")

d. red beans: # of red survivors x total # of beans killed = #of new red bean recruits
total # of survivors (all colors)
Do your calculation for the **red** beans here:
( ) x ( ) = ______________
( ) ("recruits")

Predator Population: Generation Five

a. spoons: # of beans killed by spoons x total # of predators = #of spoons in the next
total # of beans killed (all types) generation
Do your calculation for the **spoons** here:
( ) x ( ) = ______________
( ) (# of spoons for next round)

b. tongs: # of beans killed by tongs x total # of predators = #of tongs in the next
total # of beans killed (all types) generation
Do your calculation for the **tongs** here:
( ) x ( ) = ______________
( ) (# of tongs for next round)

c. forks: # of beans killed by forks x total # of predators = #of forks in the next
total # of beans killed (all types) generation
Do your calculation for the **forks** here:
( ) x ( ) = ______________
( ) (# of forks for next round)

d. chopsticks: # of beans killed by chopsticks x total # of predators = #of chopsticks in the next
total # of beans killed (all types) generation
Do your calculation for the **chopsticks** here:
( ) x ( ) = ______________
( ) (# of chopsticks for next round)

e. knives: # of beans killed by knives x total # of predators = #of knives in the next
total # of beans killed (all types) generation
Do your calculation for the **knives** here:
( ) x ( ) = ______________
( ) (# of knives for next round)