

# A Hands-On Exercise To Demonstrate Evolution by Natural Selection & Genetic Drift

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**A**lthough students “learn” (i.e., hear about) the components of evolution by natural selection in high school biology courses, few of them truly understand or remember them. We have developed an interactive, hands-on method of teaching about natural selection that we think increases the understanding and retention of this important concept. We have used this in the following classes as an introduction to evolution by natural selection: Introductory Biology, Genetics and Evolution, Evolution, Ecology, and Darwinian Medicine. By copying a hand-drawn figure of a fish

(or anything the instructor can draw), complete with “mutational errors,” students create a pool of variable fish that the instructor (“selection”) chooses among to survive; the students then copy this fish and selection happens again. After several “generations,” it is apparent that the form, shape, or pattern of the fish has evolved. Discussion following this exercise reiterates the required components of a trait to evolve by natural selection (heritable variation and differential fitness). Later in the semester, the same technique can be modified to demonstrate genetic drift (genetic changes in small populations), with the instructor randomly choosing which fish will survive each generation; after several generations, the fish has evolved (changed in morphology) in the absence of natural selection.

We like this method of teaching the components of natural selection and genetic drift because

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it requires few tools and makes the points clearly, without requiring the color and sound of a computer-interactive demonstration. More importantly, students are involved in the demonstration itself, as well as the interpretation of the demonstration.

## Evolution by Natural Selection

We perform this exercise in any class requiring an understanding of evolution by natural selection. With no introduction, the following exercise is carried out. (Students spend considerable time trying to figure out the purpose of the exercise while they are drawing the fish. We find that this searching for a purpose is helpful for the discussion that follows.)

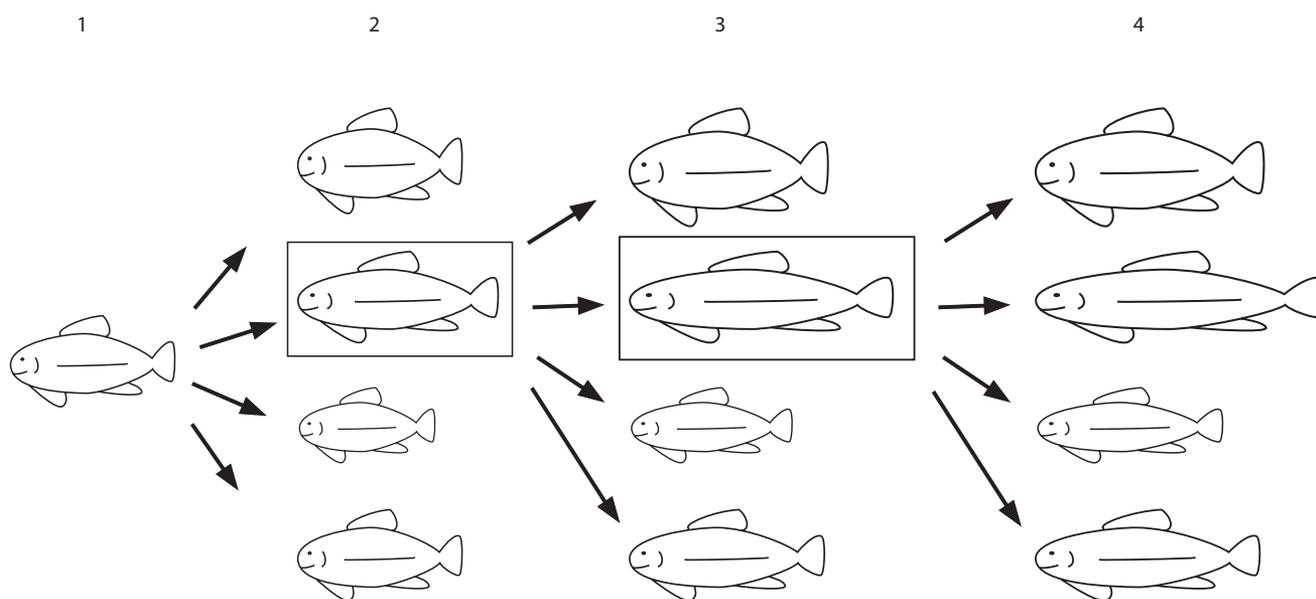
- The instructor tapes to the wall/board a hand-drawn picture of a fish, with enough detail that variation will exist in the student copies of the fish (scales, gills, lateral line, etc.). Only put as much detail on the illustration as can be recreated by the students in two minutes – keep it relatively simple.
- Students receive five pieces of paper. They are instructed to draw one copy of the fish to the best of their ability in two minutes.

- These copies are collected. The instructor chooses one of the copies to be the model for the next generation. He/she can choose based on any apparent trait that occurs among the copies: the fattest fish, the longest fish, the fish with the skinniest fins, etc. The instructor may have a predetermined direction for selection, or may opportunistically choose interesting variants. It is also possible to select for major organization change in the fish: Students may drop fins, add gill slits, and move body parts. The original fish is removed and is replaced with the chosen copy.

- Students are instructed to copy this new fish in two minutes.
- These copies are collected and the instructor chooses the one fish that best demonstrates a continuation of the trend chosen in the first generation (directional selection). If the fattest fish was chosen in Generation I, the fattest fish among Generation II should be selected. No oral clues should be given to the students as to what traits are used in the selection of the next fish.

**Figure 1.**

Diagrammatic sketch of the process of demonstrating evolution by natural selection. The original fish taped to the board is drawn under Generation 1. We have drawn only four possible renderings of fish that the students might create. The fish “selected” by the instructor for each generation is indicated by a box around it.



- Continue this for about four to five generations, each time removing the fish just copied and taping up the chosen one (if you leave all the chosen fish on the board, the trend becomes apparent to the students and they tend to exaggerate their copies of the fish).
- Stop the exercise and tape the original fish, each of the chosen fish, and examples of variants produced in each generation next to their models (Figure 1).

## Discussion

Ask the students to surmise what the exercise demonstrates. Some students will very quickly say “Evolution!” Agree with them and ask how the fish evolved through this process. Lead them in a discussion of the variation created when all the students copy the same fish. They were all instructed to copy the same fish; why didn’t the copies look identical? State why you chose the fish you did among these variants (the longest, the fattest) using the terms “only this fish survived to reproduce.” Students then copied this survivor, creating new variation as they did. It usually becomes apparent at this point what you’ve done. Variation is created (through mutation and recombination) in the production of offspring; selection acts to determine which fish will reproduce. (Discuss that this is extremely strong selection: How would you repeat this demonstration with weaker selection?) Reproduction occurs again, variation is created again, selection acts again. As you look at the original and final fish on the board, you can see that the fish did, indeed, evolve.

It is important for students to realize that although mutation and recombination are essentially random, selection is not random. Organisms best adapted to their environments will have higher fitness (more likely to survive to reproduce, more offspring, more vigorous offspring) than organisms less well adapted to their environment. What happens when the environment changes? Different phenotypes are favored and evolution will follow a different phenotypic path. A nice example of the direction of evolution changing over time is finch beak shape documented by Peter and Rosemary Grant and their students. Selection favored birds with deeper bills during the drought of 1977 (Boag & Grant, 1981), but the El Nino only several years later favored birds with smaller beaks (Gibbs & Grant, 1987). If you had sampled the birds only before the drought and after the El Nino, you would notice no net change in beak dimensions, but researchers documented two episodes of directional selection (albeit

opposite in direction) in this time period. So, evolution does not need to be directional over immense periods of time: It can happen quickly and it can reverse in its direction.

This exercise can be continued to demonstrate disruptive selection and stabilizing selection. For example, the instructor can choose the copy that best represents the original fish rather than the fattest fish, repeat this for five generations, and the students will see that the fish did not evolve in any particular direction. Does this mean that selection did not occur? No, in this case it means that stabilizing selection occurred: The biggest and smallest copies had the lowest fitness and the copies near the mean had the highest fitness. This demonstration clearly distinguishes evolution (the process) from natural selection (the mechanism).

Why do the copies look at all similar to the original or chosen fish? We have discussed the sources of variation among the “offspring” but not why there is any similarity at all. The answer is that many of the traits represented in the fish are heritable. In making “copies” of the original fish, the students’ close representation to the original fish is the thread we call heritability. Some traits are more variable than others because these traits are controlled for by more than one allele or more than one gene (or vary more with environmental variation). In our experience, each copy of the fish usually has one tail, three fins, gills, and a lateral line. For these traits, their heritability is 1.0 (there is no environmental variation among the copies). Other traits like body length and width, spacing of gills, and length of fins vary among the copies. This indicates that their heritability is something less than 1.0. This can lead to a discussion of whether nongenetic traits can evolve by natural selection. What if the source of variation is not genetic? Why might one fish be fatter for reasons other than its genes? This is a good time to talk about environmental influences on traits and Lamarck’s misinterpretation that manifestations of traits affected by the environment are passed onto offspring. In this exercise (as in nature), genetic variation arises through random events (mistakes in copying the original, mutations); often variation is introduced via random recombination.

How does this differ from natural selection in the real world? First, evolution in the natural world is usually slower, mainly because variation among offspring is usually far less, especially for important traits (traits highly correlated with fitness). Second, although natural selection is **nonrandom** (even directional), it is **not** goal-directed. Instead, the most suitable offspring are favored in each generation based on their match with

the environment **at that time**. In this demonstration, the instructor was goal-directed, intentionally choosing the fish to be copied based on its phenotype.

This exercise is even more precisely a demonstration of artificial selection, like breeders selecting for corn with high oil content. This is both faster than most natural selection, and is explicitly goal directed. In fact, Darwin's knowledge of artificial selection, particularly in pigeons, was instrumental in his development of his theory of evolution by natural selection.

By the end of this demonstration, it should be clear that evolution by natural selection requires that the trait evolving shows variation in the population, is heritable, and is associated with an increase in fitness.

## Evolution by Genetic Drift

Before the concept of drift is introduced in the course, give each student three to four pieces of paper, and tape the same original fish to the board. Have the students copy this model in two minutes. Randomly take a fish out of the students' drawings, making it clear that you are not looking at phenotypic traits of the copies. Tape this fish to the board; have the students copy it; randomly choose one of their copies, etc. After three to four generations, stop and tape the models and their copies as you did before for natural selection. Have the students address the following questions:

1. *Did the fish evolve over the entire period?*

It may not have changed noticeably, which demonstrates that drift alone does not necessarily result in evolution, but it can. The results depend on the phenotypes (and genotypes) that reproduce; by chance it may be that the smallest fish was "chosen;" then the fish will evolve to a smaller size. But if different phenotypes are chosen each generation, the traits may not evolve in a directional fashion over many generations.

2. *Was variation created each generation?*

Yes, the variation among progeny in this model should be about the same as that in the model of natural selection. The same processes of mutation, segregation, and recombination are occurring in producing the variation.

3. *Were the traits that you observed changing heritable?*

Yes, in the sense that the students' attempts to replicate the original drawing were simulating heritable traits.

4. *If the instructor wasn't being "selection," what process was determining which fish was chosen to copy each generation?*

The random process is similar to a small number of individuals (or just one) colonizing an island: Only their genes (and traits) can be passed on to the next generation. If the smallest fish in its generation is the lucky one to colonize a new area, its "small genes" will be present among the descendants, not the "big genes" in the original population.

Or, you could modify this exercise to simulate multiple founder events. *What would happen if you took several different fish and started multiple lines?*

This might be the case of an expanding species colonizing multiple archipelagos. Each island could receive a different phenotype of fish, and divergence would occur among islands, not because selection favored different phenotypes, but because drift occurred on each island.

5. *How can something evolve if natural selection has not taken place?*

If the students don't already know this, now is the time to introduce the Hardy-Weinberg Equilibrium, whose corollary is that five different processes can cause evolution of a trait: mutation, migration, genetic drift, non-random mating, and natural selection. These can act alone or in concert. So documenting that a trait has evolved is only the beginning; learning the causes of this evolution is the difficult and time-consuming part.

Both selection and drift may be happening at the same time. Imagine a group of snakes on a mainland, some of which are strong swimmers and can swim to adjacent islands. The representatives that arrive on the island are not a random subset of the mainland population; they are the strongest swimmers of the mainland population. But if only a few snakes swim to the island, you can see that "good swimming" will be well represented in the next generation (there are no "poor swimming" genes present to dilute the good swimming genes). When selection and drift act simultaneously, you expect rapid evolution of a trait.

## Conclusion

Evolution by natural selection, although seemingly simple, requires that several conditions be met. The trait of concern must exhibit variation within the population; this variation must be heritable; and the trait must be associated with differences in fitness. We have outlined a hands-on exercise that clearly demonstrates these requirements. Variation within the population is apparent in the variation among students' copies of the fish. This variation is "heritable" in that students attempted to copy the original fish on display; and only one copy per generation has fitness [only one is chosen to have "offspring" (copies made by students)]. Several generations of natural selection demonstrate that features of the fish did, indeed, evolve. Discussions following the first exercise can include why the trait that evolved could be favored under natural conditions. For instance, if the fish evolved a longer and thinner body shape, you could envision these traits being favored in warmer, more swiftly moving waters. As the environment slowly changes, the fish with the appropriate phenotypes have higher fitness relative to the other fish in the population. Students can make predictions about changes in fish phenotype under different environmental conditions (cooler water, more predators).

Evolution can occur through processes other than natural selection. The second exercise demonstrates how genetic drift can lead to changes in phenotype through a random association between phenotype and fitness. Such changes are not usually adaptive (by definition) and generally do not contribute to the major trends we see in the history of life (i.e., the evolution of horses or humans) or to the marvelous adaptations that every species exhibits. However, they do create subtly novel forms, some of which may later provide fodder for evolutionary innovation through natural selection. Taken together, these processes are responsible for the tremendous diversity of life on Earth, the remarkable adaptations of species to fit into the myriad niches for life, and the complex behaviors, morphologies, biochemical pathways, and other traits maximizing the survival of individuals' offspring.

## References

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