Evolution in Real Time:
Tracking Mutations in *E. coli* Populations

Set aside reality for a second and imagine making a cloned copy of yourself. And then making a cloned copy of that clone copy. Now imagine doing that 60,000 times. Would the 60,000th version of yourself be identical to the first? Probably not. Setting aside for a second that humans do not reproduce by self-replicating, mistakes during the process of copying DNA lead to mutations, which are changes in the sequence of an organism’s DNA. Mutations lead to genetic variation and provide the raw material for genetic change over generations, also known as evolution.

It’d be pretty great to study how and when mutations occur in real-time, but that’s easier said than done, especially with animals like humans. First of all, humans and most animals reproduce sexually, they do not clone themselves, which complicates the picture significantly. Plus, we’d get kind of cranky if we were held in a lab for a large portion of our lives, and we have a long generation time (it takes us a while to mature). Since it can take thousands of generations between the time when a mutation appears in a single individual to when it becomes common in the population, an individual scientist would not live long enough to witness the appearance and spread of mutations in a human population.

*E. coli* bacteria, on the other hand, have none of these problems. They reproduce asexually (which produces two genetically identical daughter cells, or clones), they don’t have brains so they don’t care if they’re in a lab, and they reproduce very quickly (about six generations per day). As an added bonus, they don’t take up a lot of room or have many requirements. You can host millions of them in just a few Petri dishes lined with nutrients, and that’s exactly what a bunch of scientists at Michigan State University have done. These scientists have tracked twelve populations of *E. coli* bacteria over 60,000 generations, providing us with a remarkable set of data from which to study how genetic mutations drive evolution in a constant, stable environment.

![Figure 1. Evolution in Flasks.](https://via.placeholder.com/150)

Each of the twelve populations of *E. coli* used in the long-term experiment.  
*Source:* [Wikimedia Commons](https://commons.wikimedia.org/wiki/File:E_coli_flasks.jpg).

Harvard University researchers took samples of bacterial populations every 500 generations and sequenced the DNA from each of the twelve populations. This experiment allowed scientists to identify at what point in the study mutations appeared. They could also track individual mutations to see what happens to them over time—did the mutation spread and become common among the bacteria, or did it disappear? You might think that the answer is a simple matter of whether the mutation provided any kind of fitness advantage, but it turns out that even when bacteria reproduce asexually in a constant environment, evolutionary changes can be quite complex!
The researchers found that mutations tended to follow one of three patterns. Some mutations arose and quickly spread to 100% of the population, a situation known as **fixation** (Figure 2, **mutation A**). Other mutations arose but soon disappeared in the population (Figure 2, **mutation B**). And finally, some pairs of mutations arose and hung around for thousands of generations at significant percentages of the population before one disappeared (Figure 2, **mutation C**) and the other reached fixation (Figure 2, **mutation D**).

![Graph showing mutation trajectories](image)

**Figure 2. Four Examples of Mutation Trajectories.** A, B, C, and D are single mutations. The labeled lines indicate how common the mutation was in the population over time, from Generation 0 to Generation 60,000. Once a mutation arises, it could follow one of several patterns. It may quickly become fixed, for example, spreading to every individual in the population (mutation A, purple line). Another possibility is that it may quickly disappear from the population, going “extinct” (mutation B, orange line). Two mutations may also co-exist for thousands of generations, until one reaches fixation and one goes extinct (mutations C and D, green and yellow lines). **Source:** Modified from Good et al. 2017.

The bacteria were not competing for any kind of limited resource, there was plenty of space and nutrients available. And yet, time and again, the researchers observed two mutations present together for thousands of generations before one reached fixation and the other disappeared from the population. The researchers described this situation (represented by mutations C and D in Figure 2) as one mutation “outcompeting” another. What did they mean? Well, they did not mean that one segment of DNA had a fistfight with another segment of DNA! Competition is not always direct like that. Rather, the researchers meant that the advantage one mutation gave to individual bacteria was greater than the advantage of another, and over generations, bacteria with the more beneficial mutation reproduced more frequently than the bacteria with the less beneficial mutation. Since bacteria reproduce by cloning themselves, all offspring will have the mutation that their parent had (unless a new mutation occurs), so after a while, all of the bacteria in the population will have the more beneficial mutation.

Even though the environment has been held constant, the fitness of bacteria in this environment has continued to improve. In this study, the researchers have defined “fitness” as how quickly the bacterial populations grow compared to an ancestral population. Across all twelve
populations, there was a quick jump in fitness early on—for example, bacteria from generation 500 grew MUCH faster than bacteria from the first generation. Thousands of generations down the line the bacteria are still continuing to grow faster than their ancestors, but the rates of growth have slowed down - they’re still improving in fitness, just not as fast as at the beginning! This makes sense, doesn’t it? It’s like, imagine you have a family recipe for cookies that’s been passed down for generations—maybe the first recipe was just ok, but the next couple of people to try the recipe made major improvements that made them taste much better! Since cookies are your family specialty, your family has continued to refine the recipe over the years, but the later improvements haven’t had as big of an effect as the early ones. For generations, members of your family have won cookie baking competitions all over the country. That’s what it’s like for the E. coli—they are really really good at living in their steady lab environment.

But how would they do in another environment? Well, what if you—an expert unbeatable cookie baker—entered a pie-baking competition. How would you do? Maybe you’d do okay, or even come first—but maybe you’d not even place in the top ten. A pie-baking competition is a new environment, different from the comfortable cookie-baking world in which you have improved your skills. And so for the E. coli in this experiment, were they to be moved to a different environment, success would not be guaranteed. It’s important to remember that adaptations important for success in one environment might help in a new environment, but they could also be neutral, or even harmful when conditions change.

This long term evolution experiment has been fantastic for learning about the dynamics of evolution, but these E. coli are adapted to this single constant environment, and their fitness gains in this environment might not translate to other environments. In a world where we are tiny blips in time, this experiment has helped researchers witness evolution at the level of DNA. It will be exciting to see what else we can learn from these tiny single-celled organisms!

Reference

BiteScientist Profiles

Claire Meaders majored in molecular and cellular biology at Brown University, and recently received her doctorate from Harvard University on research studying evolution and development in the Aquilegia flower. Outside the lab she’s passionate about science outreach, is attempting to run 10 marathons before she turns 30, and loves baking!

Mary Brunson is a biology teacher at Lincoln-Sudbury Regional High School in Massachusetts. She majored in Biological Resources Engineering at University of Maryland College Park and received her master’s degree in Cellular and Molecular Physiology from Yale University. When she’s not designing new curriculum and teaching, she loves playing board games and spending time with her family.

_v2: Figure 2 caption edited, September 18, 2018