

Simulation to Teach Concepts of Evolution: The Finger-Painting Fitness Landscape Application

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Challenges in Teaching Evolution

Principles of evolution can be difficult to learn. The processes involved often take place over long periods of time, placing direct observation outside of the experience of most people. When taught through abstract, mathematical modeling and memorization, students often struggle with the counter-intuitive concepts and retain prior misconceptions about evolution which traditional, direct-instruction methods often cannot unseat (Alters, Nelson, & Mitton, 2002).

Experiential learning techniques have been shown to improve understanding of difficult, abstract concepts (Koebler, Lawroski, & Bischoff, 1995) especially when computer simulations have been included (Squire, 2006). Simulations, computer games, and virtual worlds have proven useful in experiential learning when learners are unable to directly observe phenomena because of difficulties in scale. Processes that are too slow, too fast, too large, too small, or too complex can be made accessible through computer modeling, allowing learners to experience a system, devise theories about how it works, and test those theories, thereby developing an understanding of the system (Johnson, 2012).

Fitness Landscapes

The Finger-Painting Fitness Landscape Application makes use of a model first proposed by Sewall Wright in 1932 to explain how combinations of genetic characteristics interact in determining the success of a population of organisms within a particular environment: the fitness landscape metaphor. Fitness landscapes are depicted as a plot on two axes representing two traits. Hills and valleys of the theoretical fitness of an organism with traits at that location can be plotted. The fitness landscape is an over simplification, but it has been found to be a helpful visualization in developing evolutionary thinking (Zaman, Ofria, & Lenski, 2012). It directly addresses a key idea in understanding evolution, namely how populations of organisms evolve from one successful form to a more successful one.

The simple, finger-painting system used in the demonstrated simulation has been used in other programs as a quickly learned tool for interactive exploration. In particular, we are building on earlier prototypes that used more abstract representations of organisms (e.g. Zaman, Ofria, & Lenski, 2012) in order to build a simulation that can be used to teach principles of evolution to high school and college biology students.

Description of the Program

The program creates an instantiation of evolution by using a genetic algorithm with tournament selection and overlapping generations. During each round, individuals are chosen to reproduce with a probability that depends upon their location in the fitness landscape (i.e., their fitness). Those located in the darker, more favorable areas have a higher probability to reproduce. If an individual does reproduce, another is randomly chosen to die off in order to maintain a constant size population. The offspring is placed on the fitness landscape offset from the parent's location in both dimensions. The distance from the parent is determined probabilistically along a normal distribution, based on the mutation rate chosen by the player. Thus, offspring may be similar to parents or may differ greatly in both attributes, potentially allowing the population to evolve into more favorable combinations in any given fitness landscape devised by the player.

The light grey default background represents a baseline area of fitness for the population of organisms. The user can click and drag to darken the background, creating regions of higher fitness for the population. The darkest regions are the most suitable (organisms with those traits would have the highest fitness), and populations of organisms might eventually cluster there as the simulation progresses if the population is able to evolve to that fitness peak.

This simulation uses a representation of alien-looking plants in order to reduce the level of abstraction found in previous simulations that used the finger-painting fitness landscape. These plants vary in size and color depending upon where in the two-dimensional space they are born.

Learning with the Simulation

The learner can use the interactive system to visualize and simulate how a population evolves in real time. They can create a fitness landscape of their own, modify some parameters (mutation rate and size of the total population) and see what happens over time.

The simulation can be paused or reset so that the learner can start over. There is an example fitness landscape from which learners can start and observe before they start creating their own hypotheses. Learners can then hypothesize about and experiment with what might happen and what types of evolutionary paths might result from various types of complicated fitness landscapes, providing an environment for experiential learning (Kolb, 1984). Learners can change mutation rate and population size before and during a simulation to see the effects these important environmental conditions have on evolution.

Conclusion

The Finger-painting Fitness Landscape application allows the player to explore the important concept of evolution through free-form creation of a wide variety of fitness landscapes and manipulation of the landscape, population size and mutation rates, even while the simulation is running. While it is limited in that it reduces the complexities of evolution to a two-dimensional system, just as Wright's original metaphor of the fitness landscape does, there is evidence that it assists learners in developing an evolutionary mindset (Zaman, Ofria, & Lenski, 2012).

The program is currently available for PC and Mac at <https://sites.google.com/site/anyaejohnson/finger-painting-fitness-landscapes-app> and we will soon extend it to be used with or without a touch screen on a variety of other platforms (iOS and Android in particular). The program includes an example fitness landscape that a player can use for learning about how populations evolve across fitness valleys. A sample lesson is available for download to supplement that example landscape.

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