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Author(s): Anne M. Royer , Elizabeth H. Schultheis
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HOW TO DO IT

Evolving Better Cars: Teaching Evolution by Natural Selection with a Digital Inquiry Activity

ANNE M. ROYER,
ELIZABETH H. SCHULTHEIS

Abstract

Evolutionary experiments are usually difficult to perform in the classroom because of the large sizes and long timescales of experiments testing evolutionary hypotheses. Computer applications give students a window to observe evolution in action, allowing them to gain comfort with the process of natural selection and facilitating inquiry experimentation. The lesson described here uses a free online program, BoxCar2D, to demonstrate evolution by natural selection in a virtual population of cars. Students will be introduced to the principles of evolution and conduct independent inquiry projects on key predictions from evolution – including convergence, local adaptation, and the role of mutation in adaptation.

Key Words: *Evolution; natural selection; inquiry; scientific method.*

Evolution is a unifying theory in biology, a lens through which we can view the living world (Dobzhansky, 1972). Descent with modification from a common ancestor can explain all of biology's "endless forms most beautiful," from the diversity in the tree of life to adaptations like a peacock's tail (Darwin, 1859, p. 490). Yet only 28% of biology teachers are estimated to teach evolution as prescribed by the *National Science Education Standards* (Berkman & Plutzer, 2011). Many teachers lack confidence in their understanding of the theory or choose to avoid controversy (Berkman & Plutzer, 2011). Computer simulations of evolution in digital populations can help students and teachers gain comfort with the principles of evolution by natural selection (Speth et al., 2009). Here, we describe a lesson that introduces the major principles of evolution by natural selection in an approachable, and fun, inquiry format.

Students' trust in scientific theories, such as evolution, is correlated with an understanding of the methods used to support them (Lombrozo et al., 2008). Instead of viewing science as a list of facts, students should be given an understanding of how scientists create and modify factual knowledge (Pennock, 2005). Evolution can be taught as a model of scientific process: asking questions about the natural world, forming testable hypotheses to address these questions, and evaluating hypotheses using evidence.

Students struggle with misconceptions about evolution by natural selection and its key principles (variation, heritability, selection). Variation is the fuel for natural selection, yet students are often taught to focus on the shared features that characterize species rather than the variation within a species (Shtulman, 2006; Gelman, 2009), which makes them less likely to accept the theory of evolution (Shtulman & Schulz, 2008). When teaching evolution, it is easy to anthropomorphize the process of variation and selection, describing a moth as "purposefully mutating" to blend into its background and escape predators, or a flower as "wanting" to attract pollinators to produce seeds. This reliance on teleological explanations for evolution, with organisms evolving because of a need to achieve a goal, can lead students to invoke agency where none exists (Brumby, 1984). This misconception is so pervasive that the use of agency in students' responses about evolution is used in assessing their evolutionary understanding (Moore et al., 2002).

Students learn best when engaged by active exploration rather than lecture and memorization (Satterthwait, 2010). Rote learning leads to a lack of integration between concepts (Marton, 1983), which is particularly detrimental to grasping a unifying theory like evolution. It is a challenge for teachers to teach evolution in an active way; typically, the collection of evolutionary data is a time-consuming process. To study evolution, you often need many generations (time) to get a measurable response and many replicates (space) to deal with variation. For example, Peter and Rosemary Grant's famous studies of "Darwin's finches" have involved many years of following hundreds of finches through their lives in the remote Galápagos Islands (e.g., Grant & Grant, 2002). Even Richard Lenski's groundbreaking research on evolution in the fast-reproducing bacterium *Escherichia coli* has required years of daily lab work and abundant long-term freezer space (e.g., Blount et al., 2008). These resources are not available in the classroom, but the use of computer simulations allows students to observe evolution in a digital population where experiments can be large and generation times are quick.

Evolution can be taught as a model of scientific process.

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Developed by Ryan Weber, BoxCar2D is an online package that simulates a population of evolving cars. The traits of each car, such as size or wheel number, are controlled by genes. The population of cars evolves over generations by natural selection. In each generation, individual cars mate and leave behind offspring, with mutations adding variation. The success, or fitness, of a particular car on a particular track is determined by how far the car moves, with the farthest-traveling cars leaving behind more offspring. Users can manipulate factors such as mutation rate and population size, providing the opportunity to run evolutionary experiments in minutes!

Because the organisms in BoxCar2D are cars, students may not bring all of the same misconceptions they attach to evolution in biological species. When exploring the program, students observe that selection can only operate on the variation present in the population. As populations evolve, students see that species do not get the mutations that they "want," but only those that occur randomly.

Here, we present an introductory lesson to teach the concept of local adaptation using BoxCar2D. We include ideas that can be used for extensions or student-led inquiry projects on other topics (Table 1).

○ Learning Objectives

Through guided exploration of digital evolution in BoxCar2D, students will gain an understanding of the following concepts:

- Evolution is the consequence of the interactions between (1) variation in traits; (2) selection acting on this variation, leading to differential individual survival and reproduction; and (3) heritable traits that are passed on to future generations.
- Evolutionary change cannot happen in an individual; it is measured as changes in the frequency of traits in a population over generations.
- Mutations and recombination create variation.
- Much of the variation produced by mutation is not helpful, but some is – this random variation is the raw material acted on by natural selection.

○ Using the Website

Students will need computers (one per student or student pair) with an Internet connection and Adobe Flash software (free). BoxCar2D

Table 1. A selection of additional concepts that can be tested in BoxCar2D. Each population running on a screen is an independent replicate for testing evolutionary questions. Thus, it is possible to replicate evolution with identical settings in the same environment – each computer can run an independent sample. Replication is a strength of BoxCar2D – for any experiment, replicate all treatments.

Concept	Hypothesis	Prediction	Methods
Convergence & Divergence	Shared ancestry and similar selection can both result in superficial similarity; differing selection can make even close relatives appear very different.	BoxCar2D populations evolved from different ancestors on the same track will look more similar than populations evolved from the same ancestor on different tracks.	Seed populations with two different cars. Evolve the populations on two tracks. Compare (1) cars with a shared ancestor and different environment, and (2) cars with a shared environment and different ancestors.
Genetic Drift	Smaller populations lose genetic variants faster; larger populations maintain genetic variation longer.	The larger the population, the faster adaptation will occur.	Evolve populations on the same track, varying only population size. Compare population mean fitness. (Be sure to control for generation time – smaller populations can run through generations faster.)
Mutation–Selection Balance	Slow mutation rates allow selection to remove all variation; fast mutation rates destroy good variations.	Populations with intermediate mutation rates will experience faster adaptation.	Evolve populations on the same track, varying only mutation rate. Determine the mutation rate where population mean fitness increases the fastest.
Constraint	Limited genetic variation will slow, but not stop, adaptation.	Even if wheels cannot evolve, natural selection can still result in vehicles moving farther in BoxCar2D.	Evolve populations with (1) no wheels, by setting the wheel frequency to zero (constraint); and (2) two or more wheels (no constraint). Which populations adapt faster? Does constraint stop or only slow adaptation (increase in mean population fitness)? Hint: choosing the track "The Peak" works best for this experiment.

is online at http://www.boxcar2d.com. We describe how to use the program here; detailed protocols and worksheets to aid in assessment are available for free online (http://beacon-center.org/education-outreach/k-12-education/).

On the homepage, a random population can be seen evolving. The chart on the left side of the page tracks each car's score (how far it went on the track; Figure 1a). As generations pass, two lines will appear in the right-hand corner above the track: the red line is the highest-performing individual score (fitness), and the black line is the population mean fitness (Figure 1b).

BoxCar2D organizes the information describing each car into a chromosome-like string of code with a gene for each trait (e.g., size of each car section, attachment point of each wheel; Figure 2). Differences in genes come from the same two sources of variation that fuel biological evolution: mutation and recombination. As in biological evolution, the ultimate source of variation is mutation: a mutation changes a gene randomly (e.g., moving the attachment point of a wheel; Figure 2). This variation is remixed in unique combinations through a crossing-over process roughly analogous to synapsis in meiosis I (the difference: recombination in BoxCar2D happens across two parent chromosomes, not between analogous chromosomes in one parent).

○ An Introductory Guided-Inquiry Lesson: Local Adaptation

Local adaptation is an important concept in evolution, predicting that a population will perform better in the environment in which it evolved than will a foreign population (equivalent to the home team beating the away team; Kawecki & Ebert, 2004). Studying local adaptation yields insights into many aspects of evolution, including speciation, identification of adaptive traits, and maintenance of genetic diversity (Kawecki & Ebert, 2004). It is traditionally tested using a design called the "reciprocal transplant," whereby the fitness of each population is tested in both the home and the away environment. For example, if a species of plant has populations on the tops of mountains and in the valleys, we expect that plants from a mountain population that are grown in a valley will do worse than the valley plants, and likewise that valley plants grown on a mountain will do worse than mountain plants (e.g., Clausen et al., 1948, cited in Núñez-Farfán & Schlichting, 2001). This experimental design reveals whether natural selection has led populations to be adapted to their home environment. The design lends itself well to BoxCar2D.

To start, choose two very different tracks (e.g., The Hills and The Gap). Assign half of the students to each track, interspersing them

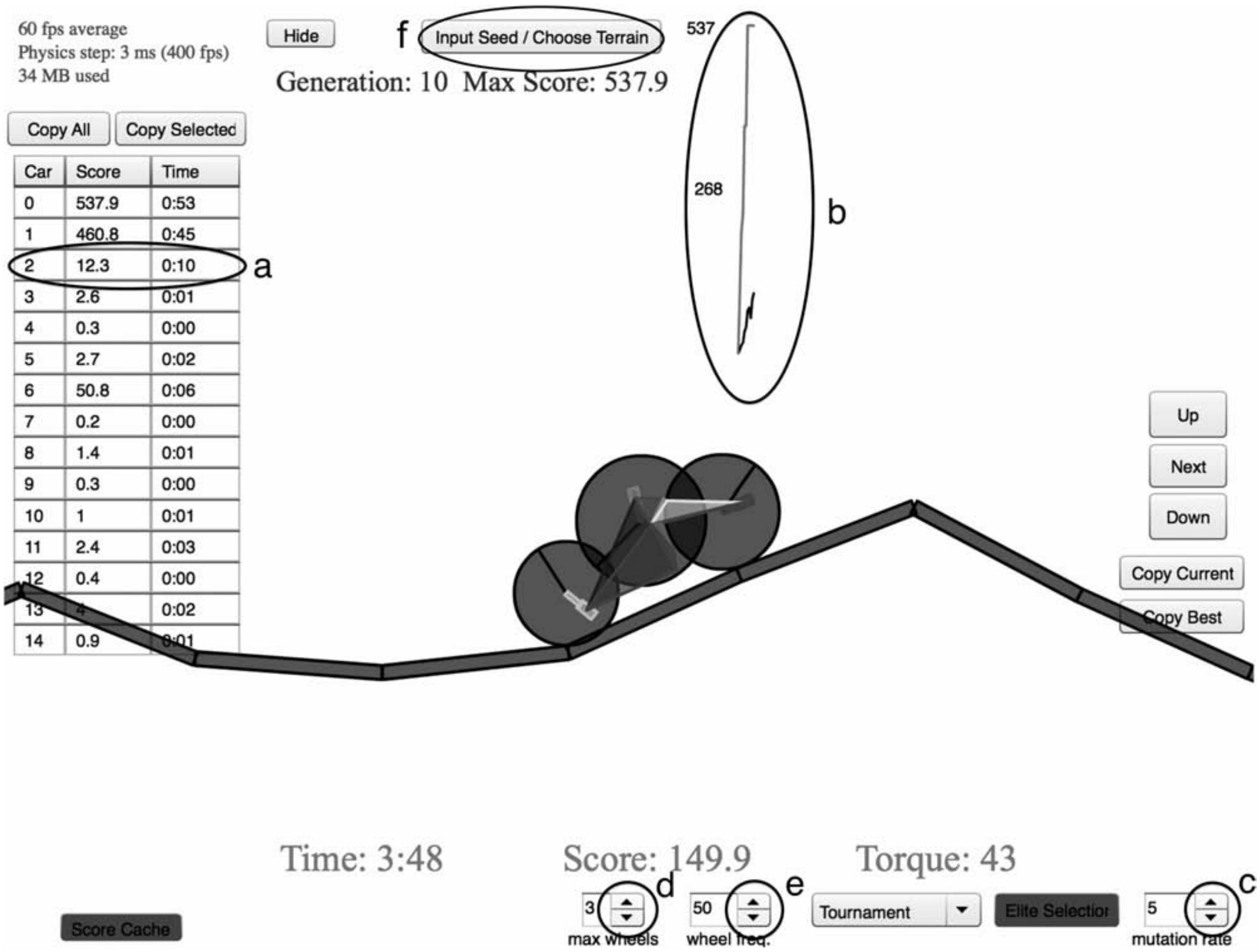
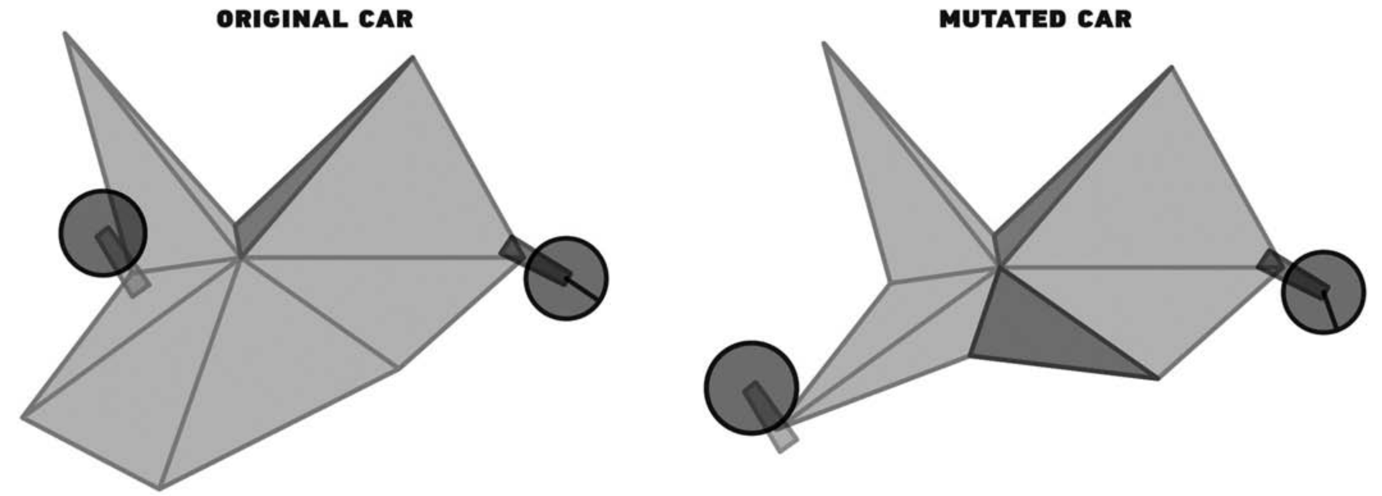


Figure 1. BoxCar2D's main page. (a) The score – distance traveled – for the third car in a population of 20. (b) Graph showing performance over time; the gray line represents the highest scoring car, and the black line shows the population mean score. (c) Option to adjust mutation rate. (d) Option to adjust the maximum possible number of wheels. (e) Option to adjust wheel frequency. (f) How to choose a new track type or start a new random population – see Figure 2.



CAR \ GENE	Angle0	Mag0	...	...	Angle5	Mag5	...	...	Wheel-Vertex0	Axle-Angle0	...	...
Original Car	0.0535	2.682	0.584	0.319	0.054	0.054	0.054	0.054	3	5.284	0.434	7
Mutated Car	0.0535	2.682	0.584	0.319	0.940	0.054	0.054	0.054	4	5.284	0.434	7

Figure 2. "Chromosomes" illustrating mutations in a BoxCar2D car. New mutations are composed of a change in the number for that cell. The color changes in the car are a marker that a mutation has occurred, but do not affect car performance independently of the number change (figure modified from ones at http://boxcar2d.com/about.html).

so that they can watch populations evolving on both tracks. Have them start random populations: click "Input Seed/Choose Terrain" (Figure 1f) under "Terrain" (Figure 3b), select the assigned track, click "Random Population" (Figure 3d), and spend at least 10 minutes observing their evolving population. They should record adaptive mutations when they show up – what do they look like, how do they function, how much do they increase fitness, how quickly do they spread? Emphasize that opening a new tab halts evolution, and closing the window deletes the population permanently.

At this point, the populations need time to evolve. The more generations that pass, the more dramatic the adaptation will be. If computer time is a limiting factor, 30–45 minutes is sufficient for visible differences. Leaving the computers running for several hours results in even more dramatic results. To finish the experiment, have the students perform another 10-minute observation and sketch their best-running car (the highest-performing vehicle from the last generation is the first to run in each generation). Finally, they should record the population mean fitness. The graph on the website gives only a rough fitness estimate, but a precise number can be obtained by recording the fitness scores for each car in the last generation if desired.

To perform the reciprocal transplant, each population should be run on the track that it did not evolve on. To do this, start on the screen with the adapted evolving population. Click "Input Seed/Terrain," change the track, and then click "cancel" (Figure 3c). The program will return to the same population, now running on a new track (if it was mid-generation at the switch, it will finish the generation on the old track before switching). After a single generation, record the population mean fitness on this new track. Because of a glitch in the program (version 3.2), the first two cars listed for the population keep their old scores from the track on which they evolved; exclude the scores for those cars from the population mean.

○ Student-Guided Independent Inquiry Using BoxCar2D

Once students are familiar with the basics of the program, they can move on to independent full-inquiry projects. Table 1 outlines a few of the concepts students could test using BoxCar2D, with suggestions for how each could be approached. Students can come up with other unique questions by combining the variables that can be manipulated and measured (Table 2).

When we have taught lessons with BoxCar2D to grades 7–12, our students have been enthusiastic and engaged. They ask questions about how it works and watch with excitement as adaptive mutations arise and spread in a population. When 28 high school students in a weeklong summer course on evolution were given the described lesson, 82% of students said the program did a good or excellent job of preparing them to answer questions about evolution. One hundred percent of students involved in group projects doing extensions with BoxCar2D reported that they found it interesting and it allowed them to apply their new knowledge about evolution. Although this program is not a panacea for individuals with religious objections to evolution, we have found that it encourages students to think about and discuss the process of evolution by natural selection.

○ Conclusions

Much disbelief about evolution comes not from a lack of evidence but from the inability of students to understand the scientific process and synthesize evidence to make an argument (Lombrozo et al., 2008). Shockingly, only around half of the U.S. population accepts evolution as a valid scientific theory (Evans, 2001). Of those, many have major misconceptions about the process (Shtulman, 2006). Clearly, science education needs a new approach when teaching evolution in classroom

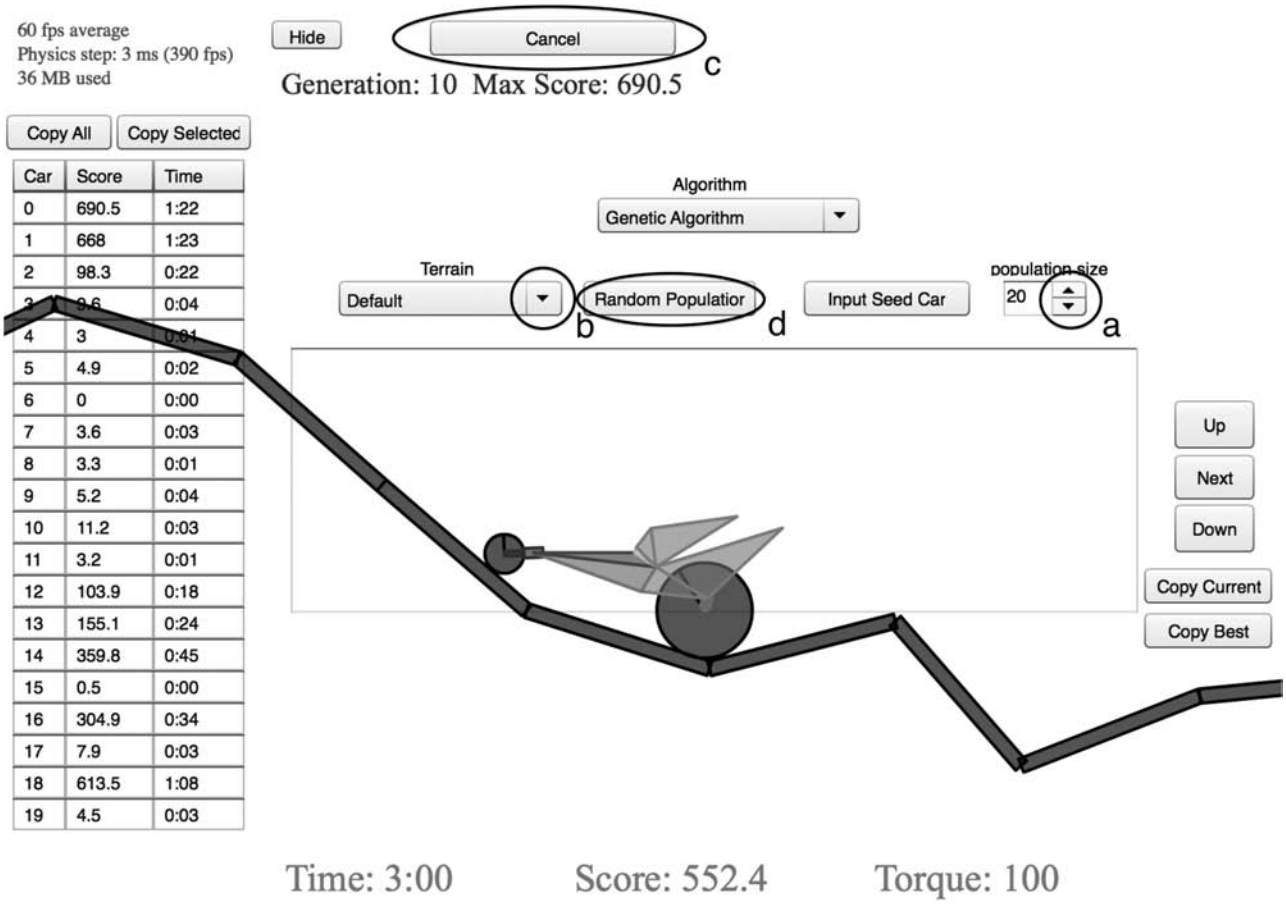


Figure 3. How to change population size and track type in BoxCar2D. (a) Change population size. (b) Change track. (c) Click after choosing track to return to the same evolving population on the new track. (d) Click to start a new random population – the population that was evolving will be lost.

Table 2. Variables that can be measured as responses to selection or manipulated to design experiments. How far a single car moves along the track (i.e., its individual fitness) dictates how likely it is to contribute to the next generation. Mean population fitness is a measure of how well adapted the population of cars is to the track. To import a car into the Designer, copy the code for the car by clicking on its row in the score table, click "copy selected," go to the "Designer" tab, paste the code into the box using a right-click menu or command-V, and click "input car."

Individual-Level Variable		**How to Measure**
Trait	Torque (force rotating the wheel)	Import car into Designer
	Mass	Import car into Designer
	Dimensions (e.g., longest and shortest axes, wheel radii)	Freeze car by clicking "Input Seed/Choose Terrain" (Figure 1f), or import car into Designer. Measurements can be taken on the screen using a ruler.
	Qualitative traits (e.g., "long and low" or "lots of wheels")	Observing populations, recording impressions
	Wheel number	Count
Fitness	Distance traveled	Scores appear in the table on the left of an evolving population
Population-Level Variable		**How to Manipulate**
	Population size	Choose 2–100 (Figure 3a)
	Track	Choose from 10 (Figured 3b)
	Mutation rate	Choose 0–100 (Figure 1c)
	Maximum number of wheels	1–8 (Figure 1d)
	Wheel frequency	0–100 (Figure 1e)

settings. In response to this and broader related problems, the science education landscape is shifting the focus from memorizing science facts to understanding and participating in the process of science itself.

Limited time and resources often make teaching evolution through inquiry challenging. Programs like BoxCar2D break down this barrier and allow students to engage in the process of science. In addition to teaching basic evolutionary concepts, this program also illustrates how evolutionary concepts can inform engineering, helping integrate STEM fields for students. This is absolutely essential for students interested in pursuing careers in STEM fields, but also key for shaping informed, critically thinking citizens.

○ Acknowledgments

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References

Berkman, M.B. & E. Plutzer. (2011). Defeating creationism in the courtroom, but not in the classroom. *Science, 331,* 404–405.

Blount, Z.D., Borland, C.Z. & Lenski, R.E. (2008). Historical contingency and the evolution of a key innovation in an experimental population of *Escherichia coli*. *Proceedings of the National Academy of Sciences USA, 105,* 7899–7906.

Brumby, M.N. (1984). Misconceptions about the concept of natural selection by medical biology students. *Science Education, 68,* 493–503.

Clausen, J., Keck, D.D. & Hiesey, W.M. (1948). *Experimental Studies on the Nature of Species, Volume III: Environmental Responses of Climatic Races of* Achillea. Publication 581. Washington, DC: Carnegie Institution of Washington.

Darwin, C. (1859). *On the Origin of Species by Means of Natural Selection.* London: John Murray.

Dobzhansky, T. (1972). Darwinian evolution and the problem of extraterrestrial life. *Perspectives in Biology and Medicine, 15,* 157–175.

Evans, E.M. (2001). Cognitive and contextual factors in the emergence of diverse belief systems: creation versus evolution. *Cognitive Psychology, 42,* 217–266.

Gelman, S.A. (2009). Essentialist reasoning about the biological world. In A. Berthoz and Y. Christen (Eds.), *Neurobiology of "Umwelt": How Living Beings Perceive the World* (pp. 7–16). Berlin, Germany: Springer.

Grant, P.R. & Grant, B.R. (2002). Unpredictable evolution in a 30-year study of Darwin's finches. *Science, 296,* 707–711.

Kawecki, T.J. & Ebert, D. (2004). Conceptual issues in local adaptation. *Ecology Letters, 7,* 1225–1241.

Lombrozo, T., Thanukos, A. & Weisberg, M. (2008). The importance of understanding the nature of science for accepting evolution. *Evolution: Education and Outreach, 1,* 290–298.

Marton, F. (1983). Approaches to learning. In J. Bowden and F. Marton (Eds.), *The University of Learning: Beyond Quality and Competence* (1998). London, UK: Kogan Page.

Moore, R., Mitchell, G., Bally, R., Inglis, M., Day, J. & Jacobs, D. (2002). Undergraduates' understanding of evolution: ascriptions of agency as a problem for student learning. *Journal of Biological Education, 36,* 65–71.

Núñez-Farfán, J. & Schlichting, C.D. (2001). Evolution in changing environments: the "synthetic" work of Clausen, Keck, and Hiesey. *Quarterly Review of Biology, 76,* 433–457.

Pennock, R.T. (2005). On teaching evolution and the nature of science. In J. Cracraft & R. Bybee (Eds.), *Evolutionary Science and Society: Educating a New Generation.* Colorado Springs, CO: Biological Sciences Curriculum Study.

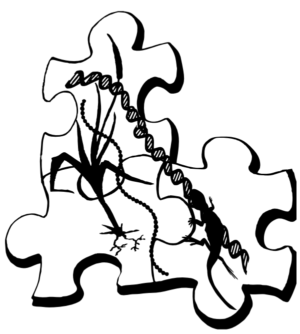
Satterthwait, D. (2010). Why are "hands-on" science activities so effective for student learning? *Teaching Science, 56*(2), 7–10.

Shtulman, A. (2006). Qualitative differences between naïve and scientific theories of evolution. *Cognitive Psychology, 52,* 170–194.

Shtulman, A. & Schulz, L. (2008). The relation between essentialist beliefs and evolutionary reasoning. *Cognitive Science, 32,* 1049–1062.

Speth, E.B., Long, T.M., Pennock, R.T. & Ebert-May, D. (2009). Using Avida-ED for teaching and learning about evolution in undergraduate introductory biology courses. *Evolution: Education and Outreach, 2,* 415–428.

ANNE M. ROYER (royerann@msu.edu) and ELIZABETH H. SCHULTHEIS (eschultheis@gmail.com) are both PhD candidates at the Kellogg Biological Station and Department of Plant Biology, Michigan State University, 3700 East Gull Lake Dr., Hickory Corners, MI 49060.



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