Cannus stannous: Understanding Chance & Necessity in Natural Selection

NABT BioClub RECOMMENDATION

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Abstract

This classroom activity highlights how evolution by natural selection is nonteleological—that is, not guided by need, by organismal intent, by inherent progress, by an external ideal, or by any observable purposive agent. Rather, it is driven by chance opportunity, environmental context, and historical happenstance. Students simulate the evolution of a population of tin cans, based on temperature retention/loss in either arctic or hot desert habitats. Chance and necessity interact in separate lab groups (as isolated populations), based on similar starting organisms. The process demonstrates not only selection but also how even organisms in similar environments may not evolve with identical traits, depending on available mutations. It shows that even when selection occurs, it may not do so consistently or uniformly with each generation. It shows both divergence based on different contexts of selection and variability based on the vagaries of history.

Key Words: *natural selection; evolution; teleology; chance; simulation*

○ Orientation

Cannus stannous. Surely you recognize the scientific name of an organism commonly found in recycling bins? The *tin can*. Here, I describe a classroom activity that highlights how evolution by natural selection is *nonteleological*—that is, not guided by need, by organismal intent, by inherent progress, by an external ideal, nor by any observable purposive agent. Rather, it is driven by chance opportunity, environmental context, and historical happenstance. Students simulate the evolution of a population of tin cans, based on temperature retention/loss in either arctic or hot desert habitats. Chance and necessity interact in separate lab groups (as isolated populations), based on similar starting organisms, but leading to divergent outcomes. Personal engagement helps render these nonintuitive concepts concrete. It's a fun "wet lab"—literally, with lots of water!

> *While students will see the expected adaptation from selection, they will also witness the various effects of chance.*

Educators have long been concerned about how to teach evolution and natural selection effectively. While this lab activity illustrates the standard concepts—adaptation, mutation, variation, inheritance, selection, reproductive fitness, and divergence—the main focus is not the mechanism of change but rather the *nature* of the evolutionary process. Most students initially regard natural processes, including evolution, as purposive (e.g., Allchin, 2021; Kelemen, 2004, 2012; Varella, 2018; Werth & Allchin, 2020). Accordingly, polls consistently find that even among Americans that view humans as evolved, roughly two-thirds also view the process as guided or involving an intentional agent (Pew Research Center, 2019; Swift, 2017). In this regard, they are not that different from those who reject evolution outright as incompatible with a religious view of providential agency (e.g., Ashley, 2016; Moore et al., 2002). Not surprisingly perhaps, teleological views are frequently cited as an obstacle in students understanding evolution (e.g., Bishop & Anderson, 1990; Stover & Mabry, 2007; Gregory, 2009; Mead & Scott, 2010a; González Galli & Meinardi, 2011; Gelman & Rhodes, 2012; Barnes, et al., 2017; Gresch, 2020). Addressing teleological perspectives thus seems essential, even foremost, in teaching about evolution (e.g., Bardapurkar, 2008; Greene, 1990). The lab activity here thus focuses chiefly on the role of chance (elaborated ahead) and its interplay with necessity in natural selection and evolution.

One effective strategy for addressing teleological views is through historical cases (Jensen & Finley, 1995). Many textbooks discuss Darwin's voyage on the *Beagle*, and some detail the development of his ideas. Using the parallel case of Alfred Russel Wallace, Friedman (2010) further integrates history with student inquiry, thereby incorporating another pedagogical ideal: active, problem-based learning. The strategy here, however, is to help students experience first hand, through a simulation of evolution, how chance factors into natural selection. It yields observations that challenge the intuitive views that adaptation naturally tends toward imagined

or desired ideals. It thereby opens the way for conceptual change through subsequent moderated discussion.

Many (many!) activities for simulating natural selection are already available (e.g., in this journal: Baumgartner & Duncan, 2009; DeSantis, 2009; Hongsermeier et al., 2017; also Geraedts & Boersma, 2006; Janulaw & Scotchmoor, 2011; plus many readily available virtual computer models). However, most focus just on the standard mechanistic concepts listed above, not teleology. They typically use predation of colored prey (LEGO blocks, beads, jelly beans) against colored backgrounds—simple examples that students readily appreciate. Almost all activities seek primarily to "rationalize" adaptive design as arising from thoroughly naturalistic processes, using the student as an active selecting agent, ironically affirming teleological views (Table 1).

Few explore the role of other evolutionary outcomes, such as divergence, convergence, biogeographical patterns, founder effects, exaptation, or vestigial structures. Some activities do try explicitly to address "Lamarckian" concepts (whether characterized as individual-level adaptation, use and disuse, inheritance of acquired traits, or "need"/*besoin*; Bishop & Anderson, 1990, p. 422). Yet a common refrain from research is that they generally fail to do so. For example, as reported recently in this journal, Bauer (2017) achieved significant pre-post gains with a simulation involving imaginary organisms. However, the activity was *not* effective on two key elements surrounding teleology: whether adaptations arise out of need and whether individuals themselves mediate the adaptive process (pp. 123, 125). Likewise, Geraedts and Boersma (2006) found it difficult to dislodge Lamarckian preconceptions while trying to demonstrate the creative role of chance variation. By comparison, the *Cannus stannous* simulation aims foremost to highlight the role of arbitrary factors (or chance), even when organisms may also ultimately exhibit apparent "design." Teachers who already use other simulations may find features here that help them revise or extend their own activities to address teleological preconceptions more effectively.

Jacques Monod famously characterized evolution as an interplay of "chance and necessity." However, the ambiguous term *chance* may well invite some caution (Mead & Scott, 2010b). In the activity here, *chance* signifies inherent uncertainty, or happenstance—that is, without an explicit or intentional trajectory—the very opposite of necessity. When biologists refer to chance variation, for example, they mean that mutations are "blind": not biased by the status of the organism or its environment, or toward improved functionality. One may contrast this with other familiar (but inappropriate) meanings of *chance* that allude to mathematical probabilities, such as random, stochastic, rare, or infrequent. Hence, when one rolls a die in the exercise here, it is not to assign a numeric frequency to the various alternative events but rather to represent their inherent unpredictability. One may thus associate chance with historical *contingency*: coincidence, or the unforeseeable intersection of historical events, or the fortuitous combination of contexts that cannot be anticipated, or, more simply, *happenstance* (on contingency, see Jacob, 1977; Gould, 1989; Andrews & Burke, 2007; Blount et al., 2018). Chance yields opportunity, not determinism. It opens potentialities rather than unfolding preordained plans. Accordingly, one might equally call evolution an interplay of contingency and necessity.

○ **Overview**

The objective of the *Cannus stannous* simulation is to underscore the interaction of unpredictable opportunity and necessity in evolution and to show that the process of natural selection is indirect (two-stage), *not* teleological and *not* observably governed by intentional agency.

> This is a summary only. For a complete description, see the Supplemental Material available with the online version of this article. This includes a student handout (S1) and teaching notes (S2, especially helpful where instructors rely on teaching assistants).

The strategy is to use a hands-on simulation, where rolls of the die are recognizably uncontrolled, indeterminate events in generating new variants (mutations). Students manage the differential survival of a model organism (the tin can) based on how well they retain (or lose) heat. The class is split into two environments (arctic and desert) to show how selection will foster divergence in different habitats, even when everyone starts with identical populations. Chance mutations are introduced every generation. Similarly, each

Table 1. Student misconceptions based on various teleological views (interpretations of "purpose") in typical simulation activities.

Preconception	Apparently Confirming Observation	Resonance with Target Concepts
inherent progress / "force" of improvement	• All populations exhibit adaptive trends.	natural selection (but note role of *unpredictable* origin of variants!—underscores role of contingency in selection, not direct transformation)
design, adaptive "purpose"	• Different populations' traits change appropriately to their respective environment.	natural selection (but note role of *blind* variation!—underscores role of "chance" in selection, not direct transformation) divergence (but note role of *isolated* populations)
"survival of the fittest" (competition rewards winners only)	• Organisms with higher fitness values tend to survive and reproduce.	natural selection (but note creative role depends on opportunity of new variants and "chance" vagaries of individual life)

lab table is an "island" (sharing an environment with others), as a way to underscore how unpredictable sources of variation in geographically isolated locations typically yield different histories and different outcomes. Students eventually compare results and reason about their similarities and differences.

While this simulation, like many other simulations, illustrates several basics of natural selection (variation, differential survival/ reproduction, inheritance, mutation, adaptation, divergence), the primary aim is to underscore a pair of central concepts about the nature of the evolutionary process:

- the role of *unintended, nondirectional variation* in natural selection, still leading to adaptation or what we interpret as "good design"—using die rolls
- the role of *divergence* in *geographically isolated* populations, where unpredictable local events (again, die rolls) introduce different variants and histories.

That is, while students will see the expected adaptation from selection, they will also witness the various effects of chance, not in accord with widespread intuitions about intentional agency and purposive action. Chance also yields arbitrary divergence, not merely adaptive selection.

First, designate one half of the classroom as arctic, the other half as hot desert—which simply determines where selection will be based on temperature retention (arctic) or temperature loss (desert). Every lab group/table is provided with an identical initial population: four "wild-type" tin cans, which are 12-ounce, bare metal skin, and half full (see Figure 1).

They add hot water to the cans (here, to start, half full) and measure the initial temperatures. After 10 minutes, they measure temperature again to determine the heat loss in each can. Two of the four individuals are then selected, based on the designated habitat. In the arctic habitat, one selects for heat retention (least temperature decrease). In the desert habitat, one selects for heat loss (the two cans with the greatest temperature drop). Each surviving can "reproduces," yielding a duplicate. Mutations are then introduced with the roll of a die, independently for each of the three traits for each of the four cans (see the chart in the student handout, Supplemental Material S1, for details on how each number codes for a different change in trait). Some cans will become larger, some smaller. Some will have more water (three-quarters full), some less (one-quarter full). Some will acquire insulation (students need to add an insulating layer), others thermal venting (they add a wet covering). All unpredictable. Roll the dice for the mutations for all four cans separately: lots of opportunities for chance variation! Add up the new fitness value for each can (see chart in student handout, Supplemental Material S1). Begin a graph of the population's average fitness value vs. time (generation number). The newly mutated surviving cans are refilled with fresh hot water (to their new levels), and the process repeats (Figure 1). Students follow their population for several generations (ideally six), recording phenotypes and fitness values, graphing them as they go. As students wait for their generations to mature, the instructor circulates, helping to reinforce understanding of the analogies of the model (Table 2).

The repeated roll of the die may seem redundant, time consuming, or boring. Roll. Roll again. Roll again. Twelve times each generation. But addressing this element of contingency over and over functions experientially to underscore its pervasive role, central to the activity's main lesson.

For a detailed summary of materials and setup, see the teaching notes (Supplemental Material S2).
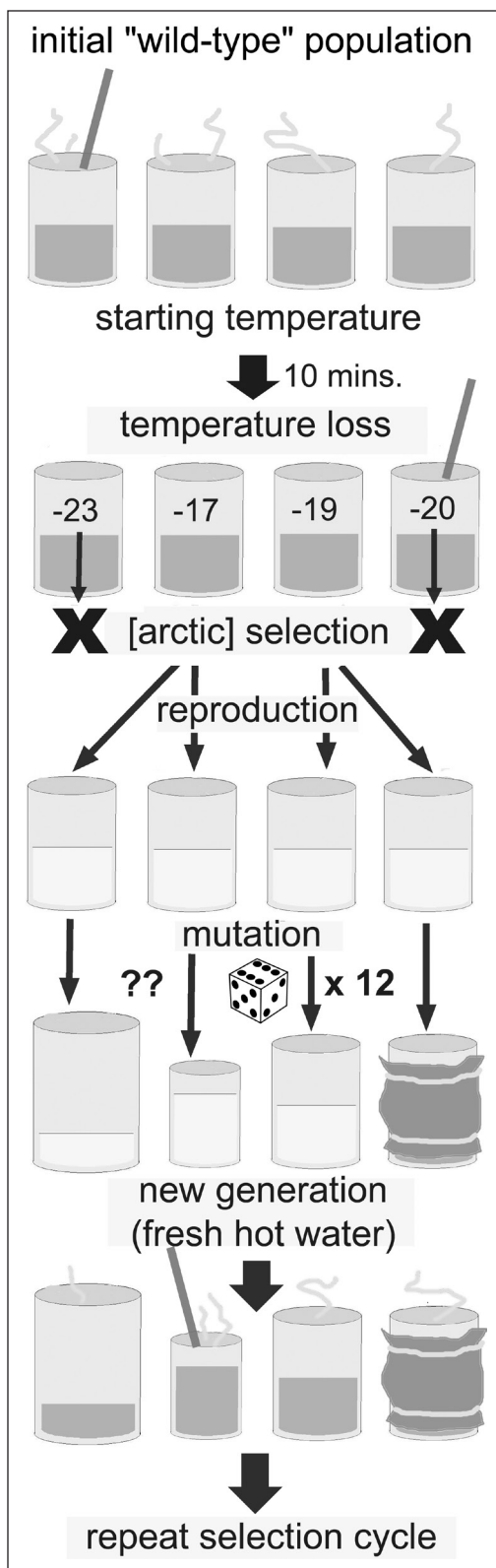

Figure 1. Visual guide to the basic procedures. Diagram does not show calculation of fitness values; graphing results for each generation; coding for how to translate dice rolls into physical mutations regarding can size, water level, or skin type (see chart in student handout, Supplemental Material S1); or questions from the instructor to prompt inquiry reflection (see teaching notes, Supplemental Material S2, and Tables 1–3).

Table 2. Analogies of the model.

Natural World	*Cannus stannous* model
blind variation	roll of die
selection	limited survival—only 2 of 4 reproduce
environment	arctic (heat retention) vs. desert (heat loss)
geographical isolation	separate lab tables

Note that this lab is more than a cookbook demonstration of (highly predictable) directional selection (see Table 1). It is not easily completed on one's own. Inquiry is involved, and instructor questioning is integral to the learning activity (see Table 3).

As the activity proceeds, students are prompted to notice and consider how to explain certain puzzling results (see student write-up as described in the student handout, Supplemental Material S1). For example, do all the mutations match or respond to the organisms' "needs"? If not, how can the population change adaptively? (Here is the core lesson about the alternating effects of chance and necessity.) Does the tin can's behavior influence the subsequent mutations? (No, it's inert! Adaptations arise by chance mutation—the roll of the die, unrelated to the can or the environment.) Usually, there is at least one case per class where average fitness *decreases* in a given generation: how does one explain *that*?! (Again, it's chance: the unpredictable roll of the die.) Later, as the varying results from different lab groups becomes clear, how does one explain how groups following the very same procedure in the same environment could lead to different results? Namely, why are all the adaptations not exactly the same? (Yet again, the role of unpredictable, or chance, variation.) If we started again, would you expect the same outcome? (No, not exactly! General trends, probably yes.) How would each new mutation affect temperature loss and survival in the other environment? Is any particular mutation inherently beneficial or detrimental? (No, survival value depends on context, not on the mutation itself.) Every population started with the same traits and experienced the same "rules" in introducing variants, yet traits in the desert and arctic habitats eventually diverged: Why? (Chance yet again!) Do the cans

Table 3. Various teleological views (interpretations of "purpose") and how they are addressed in this activity. (Citations indicate documentation of preconceptions.)

Preconception (Teleological Misconception)	Anomalous Observation, or Discrepant Event	Target New Concept
Source of Variation		
Inherent progressive force.[4,6]	• In some cases, overall fitness decreased in a given generation. • Fitness value did not exhibit uniform gain for every trait in every generation. • All populations received the same set of mutations, but each was beneficial in one environment, detrimental in the other.	The origin of variation is unpredictable – and its adaptive meaning depends on context. Role of "chance," or contingency. Still, when such variation is coupled with selection, adaptation is possible.
"Need" / Lamarckian *besoin*.[1,2,3,4,5,6]	• New variants did not always enhance survival value. • Mutations depended solely on the roll of the die, not the status of the organism.	The origin of variation is blind to need. Role of chance, lack of a targeted goal. Still, when blind variation is coupled with selection, adaptation is possible.
Mediated by organismal intent or agency (perhaps by behavior, use, will, want, or desire).[1,2,3,4,6]	• The tin cans were "passive" and did not exhibit any behavior relevant to their survival or inheritance. Mutations depended solely on the roll of the die; selection on temperature loss.	Variation arises unpredictably, contingently. Selection depends on the environment.
Mediated by external or environmental intent or "purpose."[2,4,6]	• Adaptation was achieved without applying any intention on our part. Reproduction for each successive generation was shaped solely by differential survival (temperature loss). • Mutations depended solely on the roll of the die, not the status of the environment.	Natural selection integrates both blind variation and differential survival.

Inheritance		
Inheritance of acquired traits (including use/disuse), or organisms choose which traits to pass on.[1,2,3,4,6]	• The tin cans did not change themselves in any way. Inheritance was based solely on survival, relative to temperature loss.	Natural selection is based on differential survival, leading to reproduction and inheritance.
Nature of Transformation		
Organisms transform themselves, based on individual determination or agency (selection not needed, or is redundant).[1,2,3,4,6]	• No change occurred without either differential survival or an unpredictable new variant.	Natural selection is not direct transformation, but an indirect creative process combining both blind variation and differential reproduction.
Environmental determinism ("strong design").[1,3,4]	• Different populations within the same environment did not exhibit exactly the same adapations.	Unpredictable mutations in isolated lineages yield different variants and separate histories. Role of chance.
Survival of the fittest (competition rewards winners only).[1,4]	• Can with the highest fitness value did not always retain (or lose) more heat (and hence, survive).	Natural selection is opportunistic and contingent, not strictly deterministic. Role of chance.

(1) Bishop & Anderson (1990); (2) Stover & Mabry (2007); (3) Bardapurkar (2008); (4) Gregory (2009); (5) Brumby (1984); (6) Greene (1990)

"know" how to adapt? (Not possible! Again, the cans are inert, passive, and hardly conscious.) The instructor checks around the classroom, inviting students to compare events with their expectations (documented earlier), thereby engaging students with their preconceptions.

All these questions help prime reflections for the critical discussion afterward. When the results are all collected, the instructor helps the different groups compare them. Where are there similarities, where are there differences? How do we explain them? In other words, the instructor should guide awareness of all the key comparisons and ensure effective reasoning about the interaction of chance and selection (Table 3). Each student writes up their conclusions independently, allowing individual assessment.

○ Supplemental Material

Available with the online version of this article:

- *S1.* Student handout
- *S2.* Teaching notes

○ Acknowledgments

References

Allchin, D. (2021). Why do platypuses fluoresce? Or why Darwin did not believe in "evolution." *American Biology Teacher*, 83, 555–559.

Andrews, T. & Burke, F. (2007). What does it mean to think historically? *Perspectives on History*, 45(1). https://www.historians.org/publications-and-directories/perspectives-on-history/january-2007/what-does-it-mean-to-think-historically.

Ashley, J.M. (2016). Is it providential, by chance? Christian objections to the role of chance in Darwinian evolution. In Ramsey, G. & Pence, C.H. (Eds.), *Chance in Evolution* (pp. 103–21). University of Chicago Press.

Bardapurkar, A. (2008). Do students see the "selection" in organic evolution? A critical review of the causal structure of student explanations. *Evolution: Education and Outreach*, 1, 299–305.

Barnes, M.E., Evans, E.M., Hazel, A., Brownell, S.E. & Nesse, R.M. (2017). Teleological reasoning, not acceptance of evolution, impacts students' ability to learn natural selection. *Evolution: Education and Outreach*, 10(7).

Bauer, S. (2017). The impact of the chukwin mini-unit on students' understanding of natural selection. *American Biology Teacher*, 79(2), 120–27.

Baumgartner, E. & Duncan, K., (2009). Evolution of students' ideas about natural selection through a constructivist framework. *American Biology Teacher*, 71(4), 218–27.

Bishop, B.A. & Anderson, C.W. (1990). Student conceptions of natural selection and its role in evolution. *Journal of Research in Science Teaching*, 27(5), 415–27.

Blount, Z.D., Lenski, R.E. & Losos, J.B. (2018). Contingency and determinism in evolution: replaying life's tape. *Science, 362*(6415), eaam5979.

DeSantis, L. R. (2009). Teaching evolution through inquiry-based lessons of uncontroversial science. *American Biology Teacher*, 71(2), 106–11.

Friedman, A. (2010). *Alfred Russel Wallace & the Origin of New Species*. SHiPS Resource Center. http://shipseducation.net/modules/biol/wallace.htm.

Gelman, A.S. & Rhodes, M. (2012). "Two-thousand years of stasis": How psychological essentialism impedes evolutionary understanding. In Rosengren, K.S., Brem, S.K., Evans, E.M., & Sinatra, G.M. (Eds.), *Evolution Challenges: Integrating Research and Practice in Teaching and Learning about Evolution* (pp. 3–21). Oxford University Press.

Geraedts, C.L. & Boersma, K.T. (2006). Reinventing natural selection. *International Journal of Science Education*, 28(8), 843–70.

González Galli, L. & Meinardi, E.N. (2011). The role of teleological thinking in learning the Darwinian model of evolution. *Evolution Education and Outreach*, 4, 145–52.

Gould, S.J. (1989). *Wonderful Life*. W.W. Norton.

Greene, E.D. (1990). The logic of university students' misunderstanding of natural selection. *Journal of Research in Science Teaching*, 27, 875–85.

Gregory, R.T. (2009). Understanding natural selection: essential concepts and common misconceptions. *Evolution: Education and Outreach*, 2, 156–75.

Gresch, H. (2020). Teleological explanations in evolution classes: video-based analyses of teaching and learning processes across a seventh-grade teaching unit. *Evolution: Education and Outreach, 13*, 10.

Hongsermeier, A., Grandgenett, N.F. & Simon, D.M. (2017). Modeling evolution in the classroom: an interactive LEGO simulation. *American Biology Teacher, 79*(2), 128–34.

Jacob, F. (1977). Evolution and tinkering. *Science*, 196, 1161–1166.

Janulaw, A. & Scotchmoor, J. (2011). Clipbirds. University of California, Berkeley's Lawrence Hall of Science. https://www.howtosmile.org/resource/smile-000-000-003-159.

Jensen, M.S. & Finley, F. (1995). Teaching evolution using historical arguments in a conceptual change strategy. *Science Education, 79*, 147–66.

Kelemen D. (2004). Are children "intuitive theists"? Reasoning about purpose and design in nature. *Psychological Science*, 15, 295–301.

Kelemen, D. (2012). Teleological minds: how natural intuitions about agency and purpose influence learning about evolution. In Rosengren, K. & Evans, E.M. (Eds.). *Evolution Challenges: Integrating Research and Practice in Teaching and Learning about Evolution*. Oxford University Press.

Mead. L.S. & Scott, E.C. (2010a). Problem concepts in evolution part I: purpose and design. *Evolution: Education and Outreach*, 3, 78–81.

Mead. L.S. & Scott, E.C. (2010b). Problem concepts in evolution part II: cause and chance. *Evolution: Education and Outreach*, 3, 261–64.

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.

Pew Research Center. (2019). *Evolution, Creationism, Intelligent Design*. https://news.gallup.com/poll/21814/evolution-creationism-intelligent-design.aspx.

Stover, S.K. & Mabry, M.L. (2007). Influences of teleological and Lamarckian thinking on student understanding of natural selection. *BioScene, 33*(1), 11–18.

Swift, A. (2017). In U.S., belief in creationist view of humans at new low. Gallup. https://news.gallup.com/poll/210956/belief-creationist-view-humans-new-low.aspx.

Varella, M.A.C. (2018). The biology and evolution of three psychological tendencies to anthropomorphize biology and evolution. *Frontiers in Psychology*, 9, 1–21.

Werth, A. & Allchin, D. (2020). Teleology's long shadow. *Evolution: Education and Outreach, 13*(4).

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