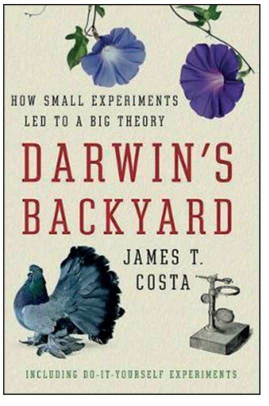
## DARWIN AS EMPIRICIST AND TINKERER

**Darwin's Backyard: How Small Experiments Led to a Big Theory.** James T. Costa. Norton, 2017. 464 pp., illus. $27.95 (ISBN: 9780393239898 cloth).

Darwin is known to us all as the great thinker who gave us the theory of evolution. But where did his ideas and vast knowledge come from? The voyage of the HMS *Beagle* is promoted as the primary source, and it certainly got Darwin off to great start. The voyage was so productive because Darwin was so industrious, inquisitive, broad in his interests, and meticulous in recording his observations. In a mere 5 years, he mastered elements of geology, systematics, and biogeography—on a global scale in marine, freshwater, and terrestrial environments—and began to weave together his understanding of the complex relationships among these disparate disciplines. At the same time, he absorbed all that was available in the small science library on board the *Beagle* and the books sent to him while he was en route. What is perhaps less well known is that Darwin's empiricism never ended. All of his biographers discuss Darwin's industry amid his lifelong illness, but the emphasis is on Darwin as a person and his interactions with other people. Science slips into the background. James Costa's *Darwin's Backyard* stands apart as a book about Darwin as a scientist and about his scientific endeavors after the *Beagle* voyage. The book is written by a scientist, with the eye of a historian, who has a full appreciation of Darwin's diverse interests and methodologies.

Each chapter presents the development of one or more of Darwin's big projects, and there were many both before and after the publication of the *Origin*, which fell approximately midway between the end of his voyage and the end of his life. Costa's presentation relies on the historian's craft of setting the context, including the observations and events that inspired Darwin, the interactions with people who helped him (as are revealed in letters and other historical documents), and the empirical path Darwin took to develop his ideas. The last is one key feature of this book that distinguishes it from its many predecessors. How did Darwin approach science? Costa shows how Darwin backed all of his ideas, no matter how big or small, with solid empirical evidence. One prime example was Darwin's efforts to formulate and test what is perhaps his biggest idea after evolution by natural selection, which was his principle of divergence and how it served as a bridge between microevolution and macroevolution (in the chapter "Untangling the Bank"). On a small scale, Darwin enumerated the number of species found on a 3-by-4-foot plot of ground in his backyard. He found them to be overdisperse—20 species from 18 genera—which reflects an equal diversity of the ecological niches they occupied and how species and niche use diversify together. On a big scale, he poured through botanical monographs and quantified the number of species per genus and the number of varieties per species to establish the continuity between diversification within species and the formation of new species. These two studies are contained in other biographies because divergence is so central to Darwin's biggest idea, but no other biography is so effective in describing his methods or developing the scientific significance of Darwin's endeavors.




A second feature of this book is how each chapter ends. Costa presents simple studies and experiments modeled on those performed by Darwin and doable by individuals or classes. The goal is to show how to follow in Darwin's footsteps with simple studies that require little more than a pencil, notebook, and common household supplies (e.g., string, toothpicks, and a yardstick or tape measure). In the "Utangling the Bank" chapter, one study was to quantify the number of species of plant on a small plot of land, just as Darwin did in his own backyard. The second study follows one from chapter 3 of the *Origin of Species*, entitled "Struggle for existence." Here, a similar small plot is prepared in the spring, before the seeds of herbaceous plants germinate. Each emerging plantlet is marked with a small wire or toothpick bearing a number, and then its fate is followed with regular censuses. At the end of the study, the compiled data can be used to construct a life table that tells us how many plants survive (usually a small minority of seedlings that germinate), but it also gives us a moving-picture perspective of the dynamics of a natural community. The implicit message of these exercises is that science is accessible. Significant science need not require expensive, elaborate equipment or demanding methodologies. Much can be accomplished with everyday tools and supplies, systematic observations, and good recordkeeping.

The book details the diverse and commonsense approaches Darwin took to science and the ways in which seemingly ordinary studies helped him either develop or promote his big idea of evolution. He collaborated with William Tegetmeier in studies on how honeybees build their complex combs. They offered bees blocks of beeswax with red dye on the surface, enabling them to perceive the shape of cells when first excavated, how the bees move wax as the number of cells increases, and how the cells acquire their geometric precision when they become crowded and space is limiting. Darwin supported the argument by comparing honeybees with other bees that also formed combs (but in smaller and less crowded clusters). He found that their combs indeed lacked the geometric precision of honeybees'. An important message is that a structure seemingly too complex to be explained by natural processes (as has been argued by others for the origin of bee combs) can instead be attributed to simple, repetitive behaviors executed by worker bees, each acting independently of the others.

Darwin and his children sealed plant seeds in bottles of saltwater and then later tested how long they could survive while drifting on ocean currents. They dangled duck's feet in pond water to see what organisms would become attached and how long they could survive out of water, a proxy for whether they could survive as ducks flew to new locations. A large collection of such simple experiments led to a more general theory for how plants and animals could colonize remote habitats and even provided more general explanations for the geographic distributions of plants and animals.

He worked with his niece, Lucy Wedgwood, to study how earthworms could contribute to reworking the landscape as they tunneled underground ingesting soil and rotting vegetation and then cast their gut contents on the surface. They set up 2-square-yard study plots in two locations, and then Lucy collected all castings from each of them for a year. At the end of the year, they dried and weighed the contents and found that they summed to an astonishing rate of 7.56 and 16.1 tons per year. These tiny contributions could indeed reshape the landscape. The more general message is that seemingly insignificant phenomena, when perceived on the scale of our day-to-day lives, could become huge and significant with the passage of time.

Darwin's research included many such interactions with friends, family, and other scientists. He corresponded constantly, asking experts in different disciplines and from different parts of the world for relevant information. He crowdsourced his research by sending out questionnaires or publishing letters in magazines read by the general public. His interests wandered to topics as seemingly eccentric as how orchids are pollinated, how carnivorous plants capture prey, or how vines locate objects and then climb them. A common theme to all of these botanical studies is that he made comparisons among a broad range of species and gave life to his theory of evolution by developing concrete illustrations of how evolution works. All three of these studies revealed that distantly related species of plants had independently evolved similar adaptations but had followed different paths in doing so. These differences were often quirky byproducts of the differences in ancestry. They revealed how evolution involves tinkering with preexisting structures rather than working from design. Darwin's studies also often revealed how seemingly complex traits could arise in a stepwise fashion from much simpler traits in their ancestors.

Costa's book is readable, interesting, and informative. It brings a breadth and clarity to Darwin's career as a scientist that are not accessible in other biographies. It also carries a great message that should encourage all readers, whether or not they are scientists or ever aspire to be scientists. Darwin is seen as one of the great, revolutionary thinkers of all time. He stands alongside figures such as Copernicus, Newton, and Einstein for having revealed fundamental truths about how the world works. What Costa adds to this image is how Darwin attained this stature. Part of his success is a part we cannot imitate—his ability to absorb and integrate vast, diverse bodies of knowledge and from that integration perceive of the rules that govern the history of life. Part of his success really can be imitated, and doing so holds great promise for all of us. Darwin's life after his voyage was often one of an invalid. He spent much of his time in his yard or immediate neighborhood and never again left the British Isles. He had wealth and the leisure time that comes with it, but otherwise, he made do with common sense, judicious use of the published literature and correspondence, cleverness in the use of ordinary supplies and equipment, systematic observation, and good recordkeeping. Few of us may have as good an eye for natural history as he did, but we all can improve with practice. All of us can follow in his footsteps in the use of common sense, careful observation, and accurate recordkeeping, and all—even trained scientists—can benefit from doing so. It is this very human side of Darwin and these very basic lessons about science that Costa conveys so well in this book.

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