Technological Change

The Evolution of Technology. GEORGE BASALLA. Cambridge University Press, New York, 1989. viii, 248 pp., illus. Cambridge History of Science.

For the better part of a century, two broadly divergent perspectives have oriented scholarship on the nature of modern technological change. The "revolutionary" view provided the initial point of departure, first attaining academic stature in Arnold Toynbee's lectures on the Industrial Revolution (1884). Then in the 1920s an "evolutionary" perspective began to emerge as an intellectual counterforce. Over the years, the general contours of the controversy have remained largely unchanged, although sustained criticism of the revolutionist viewpoint has recently tilted the balance of power perceptibly toward the evolutionary position. Now, in a major contribution to the discourse, George Basalla has done scholars a valuable service, for his forthright defense of the evolutionist position may, ironically, convince them to discard the evolution-revolution dichotomy and begin afresh.

Chief among the book's virtues is the clear and direct—indeed, elegant—manner in which Basalla's argument unfolds. He takes as his starting point the vast "diversity" of objects in the man-made world. How to explain such diversity? Biological necessity will not do, he argues cogently, not even to explain the adoption of such a fundamental invention as the wheel. Instead, he proposes "a theory of technological evolution" that emphasizes the social, political, and economic context of technological change. The bulk of the study explores the "evolutionary analogy" in depth, ranging widely over centuries and cultures and drawing examples from the history of technology, economic history, and anthropology.

Three principal concepts underlie Basalla's theory: continuity, novelty, and selection. Obviously, continuity among artifacts must obtain, he notes, for the evolutionary analogy to hold. And through a series of case studies, he does indeed demonstrate that all artifacts—real or imagined—have had antecedents in the natural or made world. Wrongheaded ideas of discontinuous or revolutionary change, he maintains, have derived their strength, on the one hand, from Western ideas and institutions (especially nationalism and the patent system) and, on the other, from a tendency to confuse technological changes with their "truly revolutionary" economic and social consequences. When one focuses on the proper unit of analysis, the artifact, one finds "technological continuity," even in those momentous changes that ushered in the Industrial Revolution in Britain.

Yet, in order for change to occur, "novelty," in Basalla's words, "must find a way to assert itself in the midst of the continuous." And, as he amply demonstrates, technological novelty has had manifold sources, above all in Western societies. Most are familiar ones: economic pressures, institutionalization of research, and changes in technological knowledge induced by diffusion or by advances in scientific understanding. Others, such as "fantasy and play," have received scant attention. In all, Basalla's masterly survey covers such an array of sources that it seems bound to escape the confines of a tidy theory, which, as he notes, "would have to encompass the irrationality of the playful and fantastic, the rationality of the scientific, the materialism of the economic, and the diversity of the social and cultural."

Having established that novelty does indeed find points of entry, Basalla comes at last to the issue on which the viability of his theory rests: the dynamics of selection. What is it in the material world, where human beings intervene, that serves as an analogue to survival value in the physical world? As Basalla himself acknowledges, "survival value becomes an amorphous concept when applied to technology." So again he eschews a general theoretical account, instead mining the evolutionary analogy for insight into the "diverse and conflicting forces"—economic, military, social, and cultural—that have shaped historical processes of selection.

It is here, on a middle-level theoretical ground, that Basalla is at his best, whether the subject be novelty or selection. Sensible yet insightful observations follow one upon the other—about the relationship between science and technology, about patent systems, about alternative paths, and (in a concluding chapter) about the cultural boundedness of notions of technological progress.

In short, Basalla uses the evolutionary analogy to good effect, but how well has he defended a "theory" of technological evolution? His treatment of novelty and selection lacks the rigor that marks his treatment of continuity, yielding little more than a catalogue of relevant factors. The study might have been more convincing had he made better use of the recent literature, provided a fuller bibliography (not to mention regular footnotes), and treated some important issues (and authors) in a less cursory fashion. Yet a deeper problem would have remained. By equating evolution with continuity, Basalla has in effect made a straw man of the revolutionary perspective: since no artifacts have emerged without any antecedents whatsoever, it follows that none qualifies as revolutionary. To my knowledge, however, no one has ever defined the term "revolution" in such a way as to require complete discontinuity. And to make matters worse, Basalla himself acknowledges that some artifacts—"seminal inventions," he calls them—have been more important than others. With that admission, he seems unavoidably to have resurrected something like the revolutionary view, and this is when one begins to suspect that the evolution-revolution discourse ought to be set aside once and for all. Fortunately, Basalla's own insights at an intermediate level of analysis may well provide the building blocks for a more rigorous and sophisticated theory of technological change.

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Coevolution: Cautious Views

Chemical Mediation of Coevolution. KEVIN C. SPENCER, Ed. Academic Press, San Diego, CA, 1988. xvi, 609 pp., illus. $95.

For the past 25 years, herbivorous insects and their host plants have been the preeminent systems claimed to exemplify coevolution. The term itself was popularized by Ehrlich and Raven in a classic paper, "Butterflies and plants: a study in coevolution" (*Evolution* **18**, 586–608 [1964]), in which taxonomic patterns of host use by butterflies were used to develop the thesis that plant evolution—particularly the evolution of defensive chemical compounds—has been stimulated by insect herbivores, which in turn adaptively radiated in response to the pharmacopoeia. In *Chemical Mediation of Coevolution*, some (only some) of the leading students of plant-insect interactions, joined by one student of herbivorous mammals and one of chemical mimicry, describe their work on some of the questions that have emerged from the coevolutionary scenario.

Not long ago, "coevolution" was often invoked to describe almost any feature of an insect or plant that affected their interaction. Several authors, including D. Janzen, M. Slatkin, and myself, cautioned that evidence for coevolution demands evidence for reciprocal evolutionary responses among interacting species, which is not easily obtained. To judge from this book, caution and skepticism now reign: the authors of at least 8 of the 16 research-based essays doubt that their systems have coevolved, and several others do not address the question at all. Many of the essays focus instead on the nature and processes of adaptation of one species (or set of species) to another, rather than on reciprocal selective effects. It would be premature, I believe, to conclude that such effects do not exist, but it is unquestionably difficult to tease out the evolutionary responses of two species to each other from the multispecific nexus in which they are typically embedded. As F. Gould points out, moreover, a complex of herbivores may intensify the selective impact of a single species on a plant, and we should not "assume that the only scientifically noteworthy outcomes of coevolution are coevolved species associations" (p. 17). In an outstanding review of the theory of coevolution from a genetic perspective, Gould demonstrates the importance of determining how diverse the impact of a plant secondary compound may be on different herbivores and how diverse the responses of an herbivore may be to different plant compounds.

Skepticism about coevolution is expressed by, among others, Brower *et al.*, who attribute to "exaptation" (preadaptation, retrospectively viewed) both the defensive sequestration of host plant toxins by monarch butterflies and the ability of orioles to circumvent this defense; by Price *et al.*, Lindroth, and Scriber, who doubt that the herbivores they study substantially affect plant fitness; and by Bryant *et al.*, who advocate an economic theory of plant allocation to defensive chemicals. Their hypothesis is appealing and finds considerable support, but I believe it is not, as they suggest, an alternative to a coevolutionary model of plant defenses. Nutrients and other environmental influences on the plant's economy may only circumscribe the arena within which coevolution might occur. Other noteworthy chapters on plant ecological chemistry include a skeptical essay by Myers on the influence of induced defenses on insect population dynamics, a summary by Chew of interactions among crucifers and associated insects, and a description by Cates and Redak of the probable impact of variation in terpenes on spruce budworm populations. In another vein, Faeth presents interesting data on the likelihood of competition and coevolution among species of herbivorous insects.

Perhaps the closest match to the Ehrlich and Raven scenario is Bowers's description of adaptations to toxic iridoid glycosides by specialized insects that in some instances use these host compounds as feeding and oviposition stimulants. This observation is not unprecedented, but rather few examples are known. Genetic processes of adaptation, which have received rather little attention in this field, are plumbed most deeply by Gould's study of cross-resistance of a noctuid moth to diverse plant compounds and by Berenbaum and Zangerl's examination, in wild parsnip, of genetic variation in and correlations among biosynthetically related furanocoumarins, their toxicity, and their costs and benefits. I do not know what to make of Spencer's chapter on interactions among *Heliconius* butterflies and Passifloraceae. This system is noteworthy because it is the subject of some classic coevolutionary stories, which Spencer attempts to extend by examining the diverse cyanogenic glycosides of many species of Passifloraceae. He advances plausible, if untested, hypotheses about why the toxicity of different cyanogenic glycosides might vary and how *Heliconius* species might differ in averting toxicity at the enzymological level. Relating the host records of butterfly species to the plants' chemistry, he concludes that host use is "correlated" with chemistry, that more "advanced" *Heliconius* species are more specialized with respect to host chemistry, and that the butterflies and plants have coevolved in a rather strict sense. If true, these conclusions would be most interesting, but I cannot understand Spencer's correlations, and his conclusions depend strongly on the phylogeny of both taxa, which has not been determined in either case by rigorous phylogenetic methods.

This volume does not exhaustively survey the subject; it is weaker on phylogenetic and genetic than on ecological approaches, it represents American work almost exclusively, and the chemical aspects, despite the title, are generally not explored deeply. It includes, however, some of the better work that is going on at present and will be a useful reference. If unity among the essays is not clearly apparent, that is a fair reflection of the subject, the threads of which have not yet been knitted into a theoretical fabric.

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Working with Fossils

Digging into the Past. An Autobiography. EDWIN H. COLBERT. Dembner, New York, 1989 (distributor, Norton, New York). viii, 456 pp., illus., + plates. $25.

Edwin Colbert's second autobiography offers the reader more details of his personal life, interests, and motivations than the earlier *A Fossil Hunter's Notebook: My Life with Dinosaurs and Other Friends* (Dutton, 1980). His teachers, fellow fossil collectors, museum associates, and prominent acquaintances around the world are portrayed in vignettes and anecdotes. In particular, colleagues at the American Museum of Natural History, where Colbert spent most of his career, are delineated in a fashion that clearly recalls them to anyone acquainted with that institution. Some of the escapades of paleontologists, especially in the course of collecting fossils, make hilarious reading.

Colbert traces the circumstances, both serendipitous and planned, that shaped his career. A visit to the Field Columbian Museum in Chicago in 1922 introduced him to vertebrate fossils, and after a few years studying forestry and working in national forests he entered the University of Nebraska with the intention of becoming a paleontologist. Here he acquired the basics of fossil preparation, exhibition, collecting, and curation under the guidance of E. H. Barbour. After graduate study at Columbia University under William K. Gregory and service as assistant to H. F. Osborn, he spent more than a decade in "armchair" study of Asiatic fossil mammals collected by Roy Chapman Andrews's Central Asiatic Expeditions and by Barnum Brown in India and Burma. (Collecting had been severely restricted during the depression of the 1930s.) In 1942 upon Brown's retirement Colbert was appointed curator of fossil reptiles at the American Museum. He selected Triassic fossil vertebrates as a subject for research, and the discovery of the little dinosaurs on the Ghost Ranch in New Mexico in 1947 provided the springboard for a long series of studies of the reptiles and amphibians of the beginning of the Age of Reptiles, including collection of fossils on every continent, including Antarctica. His popular book on dinosaurs and the museum's public exhibition of these spectacular fossil reptiles further contributed to Colbert's growing reputation as an authority on dinosaurs.

His investigations of Triassic reptiles involved Colbert in problems of biogeography and the question of continental drift. He describes the steps by which he was converted from a staunch defender of continental stability to an even more enthusiastic advo-