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INTEGRATED SCIENCE AND THE COMING CENTURY OF THE ENVIRONMENT

ILLUSTRATION: ALLAN M. BURCH

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The sesquicentennial of the American Association for the Advancement of Science is a good time to acknowledge that science is no longer the specialized activity of a professional elite. Nor is it a philosophy, or a belief system, or, as some postmodernist thinkers would have it, just one world view out of a vast number of possible views. It is rather a combination of mental operations, a culture of illuminations born during the Enlightenment four centuries ago and enriched at a near-geometric rate to establish science as the most effective way of learning about the material world ever devised. The sword that humanity finally pulled, it has become part of the permanent world culture and available to all.

"Science, to put its warrant as concisely as possible, is the organized systematic enterprise that gathers knowledge about the world and condenses the knowledge into testable laws and principles."* Its defining traits are first, the confirmation of discoveries and support of hypotheses through repetition by independent investigators, preferably with different tests and analyses; second, mensuration, the quantitative description of the phenomena on universally accepted scales; third, economy, by which the largest amount of information is abstracted into a simple and precise form, which can be unpacked to re-create detail; fourth, heuristics, the opening of avenues to new discovery and interpretation.

And fifth, and finally, is consilience, the interlocking of causal explanations across disciplines. "This consilience," said William Whewell when he introduced the term in his 1840 synthesis *The Philosophy of the Inductive Sciences*, "is a test of the truth of the theory in which it occurs."† And so it has proved within the natural sciences, where the webwork of established cause and effect, while still gossamer frail in many places, is almost continuous from quantum physics to biogeography. This webwork traverses vast scales of space, time, and complexity to unite what in Whewell's time appeared to be radically different classes of phenomena. Thus, chemistry has been rendered consilient with physics, both undergird molecular biology, and molecular biology is solidly connected to cellular, organismic, and evolutionary biology.

The scales of space, time, and complexity in the explanatory webwork have been widened to bracket some 40 orders of magnitude. Consider, for example, the webwork's reach from quantum electrodynamics to the birth of galaxies; or the great breadth it has attained in the biological sciences, which are not only united with physics and chemistry but now touch the borders of the social sciences and humanities.

This last augmentation, while still controversial, deserves special attention because of its implications for the human condition. For most of the last two centuries following the decline of the Enlightenment, scholars have traditionally drawn sharp distinctions between the great branches of learning, and particularly between the natural sciences as opposed to the social sciences and humanities. The latter dividing line, roughly demarcating the scientific and literary cultures, has been considered an epistemological discontinuity, a permanent difference in ways of knowing. But now growing evidence exists that the boundary is not a line at all, but a broad, mostly unexplored domain of causally linked phenomena awaiting cooperative exploration from both sides.

Researchers from four disciplines of the natural sciences have entered the borderland:

- Cognitive neuroscientists, outriders of the once but no longer "quiet" revolution, are using an arsenal of new techniques to map the physical basis of mental events. They have shifted the frame of discourse concerning the mind from semantic and introspective analysis to nerve cells, neurotransmitters, hormones, and recurrent neural networks. Working on a parallel track, students of artificial intelligence, with an eye on the future possibility of artificial emotion, search with neuroscientists for a general theory of cognition.
- Combining molecular genetics with traditional psychological tests, behavioral geneticists have started to characterize and even pinpoint genes that affect mental activity, from drug addiction to mood and cognitive operations. They are also tracing the epigenesis of the activity, the complex molecular and cellular pathways of mental development that lead from prescription to phenotype, in the quest for a fuller and much-needed understanding of the interaction between genes and environment.
- Evolutionary biologists, especially sociobiologists (also known within the social sciences as evolutionary psychologists and evolutionary anthropologists), are reconstructing the origins of human social behavior with special reference to evolution by natural selection.
- Environmental scientists in diverse specialties, including human ecology, are more precisely defining the arena in which our species arose, and those parts that must be sustained for human survival.

The very idea of a borderland of causal connections between the great branches of learning is typically dismissed by social theorists and philosophers as reductionistic. This diagnosis is of course quite correct. But consider this: Reduction and the consilience it implies are the key to the success of the natural sciences. Why should the same not be true of other kinds

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*E. O. Wilson, *Consilience: The Unity of Knowledge* (Knopf, New York, 1998), p. 53. †W. Whewell, *The Philosophy of Inductive Sciences* (Parker, London, 1840), p. 230. ‡F. Bacon, *Advancement of Learning* (Tomes, London, 1605). §E. O. Wilson, *Consilience*, p.280.

of knowledge? Because mind and culture are material processes, there is every reason to suppose, and none compelling enough to deny, that the social sciences and humanities will be strengthened by assimilation of the borderland disciplines. For however tortuous the unfolding of the causal links among genes, mind, and culture, and however sensitive they are to the caprice of historical circumstance, the links form an unbreakable webwork, and human understanding will be better off to the extent that these links are explored. Francis Bacon, at the dawn of the Enlightenment in 1605, prefigured this principle of integrative science (by which he meant a large part of all the branches of learning) with an image I especially like: "No perfect discovery can be made upon a flat or a level: neither is it possible to discover the more remote or deeper parts of any science, if you stand but upon the level of the same science and ascend not to a higher science."‡

The unavoidable complement of reduction is synthesis, the step that completes consilience from one discipline to the next. Synthesis is far more difficult to achieve than reduction, and that is why reductionistic studies dominate the cutting edge of investigation. To reduce an enzyme molecule to its constituent amino acids and describe its three-dimensional structure is far easier, for example, than to predict the structure of an enzyme molecule from the sequence of its amino acids alone. As the century closes, however, the balance between reduction and synthesis appears to be changing. Attention within the natural sciences has begun to shift away from the search for elemental units and fundamental laws and toward highly organized systems. Researchers are devoting proportionately more time to the self-assembly of macromolecules, cells, organisms, planets, universes—and mind and culture.

"WE ARE DANGEROUSLY BAFFLED BY THE MEANING OF [OUR] EXISTENCE...[WE NEED] AN EXPLANATORY INTEGRATION NOT JUST OF THE NATURAL SCIENCES BUT ALSO OF THE SOCIAL SCIENCES AND HUMANITIES..."

If this view of universal consilience is correct, the central question of the social sciences is, in my opinion, the nature of the linkage between genetic evolution and cultural evolution. It is also one of the great remaining problems of the natural sciences. This part of the overlap of the two great branches of learning can be summarized as follows. We know that all culture is learned, yet its form and the manner in which it is transmitted are shaped by biology. Conversely, the genes prescribing much of human behavioral biology evolved in a cultural environment, which itself was evolving. A great deal has been learned about these two modes of evolution viewed as separate processes. What we do not understand very well is how they are linked.

The surest entry to the linkage, or gene-culture coevolution as it is usually called, is (again in my opinion) to view human nature in a new and more heuristic manner. Human nature is not the genes, which prescribe it, or the universals of culture, which are its products. It is rather the epigenetic rules of cognition, the inherited regularities of cognitive development that predispose individuals to perceive reality in certain ways and to create and learn some cultural variants in preference to competing variants.

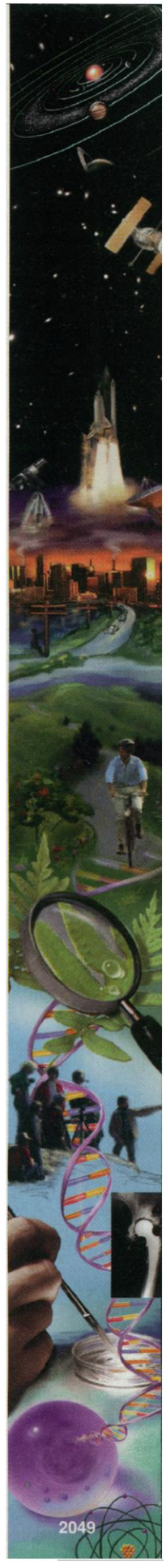
Epigenetic rules have been documented in a diversity of cultural categories, from syntax acquisition and paralinguistic communication to incest avoidance, color vocabularies, cheater detection, and others. The continuing quest for such inborn biasing effects promises to be the most effective means to understand gene-culture coevolution and hence to link biology and the social sciences causally. It also offers a way, I believe, to build a secure theoretical foundation for the humanities, by addressing, for example, the biological origins of ethical precepts and aesthetic properties of the arts.

The naturalistic world view, by encouraging the search for consilience across the great branches of learning, is far more than just another exercise for philosophers and social theorists. To understand the physical basis of human nature, down to its evolutionary roots and genetic biases, is to provide needed tools for the diagnosis and management of some of the worst crises afflicting humanity.

Arguably the foremost of global problems grounded in the idiosyncrasies of human nature is overpopulation and the destruction of the environment. The crisis is not long-term but here and now; it is upon us. Like it or not, we are entering the century of the environment, when science and polities will give the highest priority to settling humanity down before we wreck the planet.

Here in brief is the problem—or better, complex of interlocking problems—as researchers see it. In their consensus, "[t]he global population is precariously large, will grow another third by 2020, and climb still more before peaking sometime after 2050. Humanity is improving per capita production, health, and longevity. But it is doing so by eating up the planet's capital, including irreplaceable natural resources. Humankind is approaching the limit of its food and water supply. As many as a billion people, moreover, remain in absolute poverty, with inadequate food from one day to the next and little or no medical care. Unlike any species that lived before, *Homo sapiens* is also changing the world's atmosphere and climate, lowering and polluting water tables, shrinking forests, and spreading deserts. It is extinguishing a large fraction of plant and animal species, an irreplaceable loss that will be viewed as catastrophic by future generations. Most of the stress originates directly or indirectly from a handful of industrialized countries. Their proven formulas are being eagerly adopted by the rest of the world. The emulation cannot be sustained, not with the same levels of consumption and waste. Even if the industrialization of developing countries is only partly successful, the environmental aftershock will dwarf the population explosion that preceded it."§ Recent studies indicate that to raise the rest of the world to the level of the United States using present technology would require the natural resources of two more planet Earths.

The time has come to look at ourselves closely as a biological as well as cultural species, using all of the intellectual tools we can muster. We are brilliant catarrhine primates, whose success is eroding the environment to which a billion years of evolutionary history exquisitely adapted us. We are dangerously baffled by the meaning of this existence, remaining instinct-driven, reckless, and conflicted. Wisdom for the long-term eludes us. There is ample practical reason—should no other kind prove persuasive—to aim for an explanatory integration not just of the natural sciences but also of the social sciences and humanities, in order to cope with issues of urgency and complexity that may otherwise be too great to manage.



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