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Review:

Integrating Scientific Disciplines

William Bechtel (ed.) (1986)
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SCIENCE AND INTEGRATIVE STUDIES

Science is commonly viewed as infertile ground for integrative studies. To be sure, there already exist many studies of the effects of scientific thought on human affairs. For example, Copernicus' heliocentric solar system struck at the heart of Medieval perceptions on the role of man and God in the universe (Kuhn, 1957), and Darwin's principle of natural selection spurred a harsher rationalization of Victorian social strata (Appleman, 1979). Yet these studies, interesting though they are, rely primarily on elucidating the connection between scientists and non-scientists. The pursuit of scientific knowledge itself, however, has received little general attention from scholars interested in the formation and interaction of disciplines. *Integrating Scientific Disciplines*, a collection of essays edited by philosopher William Bechtel, seeks to redress this deficiency. In fact, as the book argues, science has a remarkable history of interdisciplinary influence which is still prevalent in contemporary research. In this review I will place the essays in the context of other works on interdisciplinary science, thereby hopefully encouraging the reader to dig more deeply into this fascinating area.

The study of scientific disciplines underwent a rebirth in 1962 when Thomas Kuhn published his influential book on *The Structure of Scientific Revolutions*. This short treatise, in its simple prose, transformed philosophical conceptions of the scientific process. Instead of a detached application of logic, science became a passionate competition between different research groups. These groups claimed allegiance to different "paradigms," an all-embracing term used by Kuhn to encompass a collection of interwoven cognitive and social factors. A "scientific revolution" occurred when one paradigm was replaced by another, but not without a considerable battle. What made Kuhn's thesis so interesting was that he ascribed paradigm shifts not only to "hard" scientific data, but also to the social dynamics of research scientists with their own personal agendas and prejudices. A scientific revolution was therefore rooted in the structure of disciplines and their associated paradigms, often fueled by scientists infusing new ideas into a field by carrying them from another discipline.

Kuhn also argued strongly for making historical case studies indispensible in the philosophy of science. This is amply reflected in the book under review, a member of the series in *Science and Philosophy*. The material, it is explained,

> will reflect the belief that the philosophy of science must be firmly rooted in an examination of actual scientific practice. Thus the volumes in the series will include or depend significantly upon an analysis of the history of science, recent or past (p. ii).

The organization and content of the book are true to this ideal. The essays are split into five sections. The first three treat the development of early twentieth century biology: the origins of biochemistry, the effect of melding genetics with evolution, and the subsequent addition of developmental biology to the the new "evolutionary synthesis." The interdisciplinary scholarship in these sections is outstanding, fusing historical studies of disciplinary development with philosophical commentary on the principles and processes involved. The final two sections, both studying contemporary development of cognitive science, are less successful. Several of the essays are written by scientists, and often lack an incisive perspective on the mechanism of disciplinary transformation (as a scientist myself, I am allowed to say these things). Nevertheless, these studies should not be dismissed, since they represent pioneering investigations into domains frequently left untouched by conventional philosophy of science.

The primary jewel of the book, however, precedes these case studies. In the first fifty pages, the editor offers a perceptive overview of "The Nature of Scientific Integration" with a comprehensive bibliography of recent research in the field. In short, this essay is the best general introduction to scientific disciplines that I have read. It provides a balanced appraisal of such topics as the structure of disciplines, the motivation for crossing disciplinary boundaries, and the results of cross-disciplinary endeavors. Using this foundation, Bechtel is able to show us that the issues involved in analysing scientific disciplines are no different from those involved in any study of integration. Are disciplinary boundaries cognitive or social? What factors prompt disciplinary dissention and intellectual migration? What, if anything, is unique about cross-disciplinary inquiry? Because these issues are so foundational in any discussion of disciplines, this review is an easily accessible introduction for anybody interested in the structure of science. In addition, Bechtel provides a short commentary after every section, which summarises and analyses the issues at stake, constituting another useful addition to the book.

There are a total of thirteen essays, and it is impossible to cover them all in a brief review. Instead, I will compare pairs of essays which serve to illustrate a particular debate in scientific integration. The studies within this book have a bias in favour of the cognitive basis of disciplines, and so I will fulfil the role of devil's advocate by balancing the picture with appropriate references to studies with a more sociological flavor (Lemaine, 1976).

The Intellectual Domain of Biochemistry.

An interesting debate over disciplinary transformation in science is provided by the first two essays. What is at issue is not the formation of a discipline *per se*, but rather the disciplinary factors involved in staking a claim to a topic of scientific enquiry. Written by a historian (Frederic Holmes) and a philosopher (William Bechtel), they serve to illustrate two different approaches to defining the intellectual domain of biochemistry.

In fact, the interaction of chemistry and biology has a long history. Holmes's recent book, *Lavoisier and the Chemistry of Life* (1985), for example, covers the impact caused by Antoine Lavoisier's synthesis of chemical and biological thought. He argues that Lavoisier, principal architect of the "chemical revolution" in the late eighteenth century, was profoundly influenced and stimulated by contemporary problems in physiology. The debate hinged on the role of what we now call oxygen, and Lavoisier's primary insight was to realise that the chemical process of combustion and the physiological one of respiration involved the same element. Moreover, to perform quantitative measurements on the heat emitted in these processes, Lavoisier enlisted the help of the physicist Pierre de Laplace; together, they laid the foundations of chemical transformation (Guerlac, 1976; Melhado, 1985). The "chemical revolution" should therefore be seen as the "chemical" revolution, since it in fact involved not only chemistry but also physics and physiology.

Holmes therefore brings to his essay a distinguished reputation for the historical analysis of cross-disciplinary influences. His discussion is typically detailed and technical, and does not spare the reader from chemical equations. This approach, however, permits him to attack his main theme of "intermediary metabolism," the chemical origins of physiological metabolic processes. Holmes claims that, in the early part of the twentieth century, contributions to research on intermediary metabolism were made by scientists from a wide diversity of different disciplines:

> Those who made contributions to this growing investigative stream between 1900 and 1930 published from departments of physiology, chemistry, organic chemistry, physiological chemistry, biochemistry, agricultural chemistry, botany, internal medicine, pathology, pathological chemistry, and others. Papers entered the literature from research institutes, the laboratories of hospital clinics, even from breweries (p. 59).

With such a diversity of interest, claims Holmes, none of the established disciplines could claim a monopoly over the study of intermediary metabolism. Rather than disciplines shaping the scientific research, the research reshaped the relationship between the disciplines. We should therefore be wary, warns Holmes, of ascribing too much rigidity to the disciplinary fragmentation of science. Intermediary metabolism existed as an interdisciplinary area of enquiry for over thirty years without being sacrificed to the clutches of any one discipline. In the end, it was only the independent formation of an institutional foundation for biochemistry which allowed intermediary metabolism to be absorbed as a subfield, but even then the disciplinary hegemony was not complete. "Scientific problem areas," concludes Holmes, "are more natural than, and often more stable than, the socially constructed disciplines which lay claim to them" (p. 74).

Bechtel's essay, which is no less technical, argues for a different role of intermediary metabolism in biochemistry. Classical studies in chemistry traditionally dealt with chemical reactions, whereas those in physiology were concerned with whole units such as organisms or cells. In the 1930s, after several decades of research, it became apparent that intermediary metabolism exhibited a level of organization that fell between the two. It was at this new level of biological organisation that biochemistry carved its intellectual niche, which naturally included the aforementioned metabolic processes. To summarise, Bechtel's thesis rests on the claim that

> intermediary metabolism provided biochemistry with its own distinct level of organization in nature, one that was at a higher level than the level of inorganic and organic chemistry, but below that usually considered in physiology (p. 91).

For Bechtel, therefore, disciplines can be viewed as each possessing its distinctive region of intellectual pursuit. In many ways, this is the conventional view held by practitioners of a specific discipline, and it reinforces the conceptual divisions between disciplines.

I will let the reader decide which argument is the most convincing. In his editorial comments, however, Bechtel quotes another possible explanation for the origins of biochemistry offered by historian Robert Kohler:

> intellectual achievement or the lack of it is not the reason why biochemists failed to build a discipline in nineteenth century Germany or why they succeeded in America.... Differences in achievement cannot explain why the timing, location, and character of discipline building differed so markedly in the United States, Britain, and Germany. These patterns have to do with the political and economic support system for science: movements for reform of universities and medical schools, changing hospital practice, expanding markets for scientific professionals, and evolving division of labor among disciplines (p. 104; see also Kohler 1982).

The extensive discussion of this chapter in the development of scientific disciplines serves to emphasise the uniformity of themes in science and other more thoroughly studied areas of interdisciplinary enquiry. We see contrasting arguments presented both for and against the intellectual reification of disciplines, as well as for the dominance of social influences. A useful continuation of this story is the process by which molecular biology emerged from its early twentieth century precursors, including biochemistry. There exist many useful resources in this area, but I will specifically mention two books which can serve as an introduction. *A Century of DNA*, by Franklin

Portugal and Jack Cohen (1977), provides a thorough study of how biochemical information provided the foundation for a molecular interpretation of inheritance. Robert Olby's *The Path to the Double Helix* (1974) ranges wider in its scope, and provides one of the finest examples of scholarship in the study of interdisciplinary science. Most interesting is his section of four chapters on the theme of "intellectual migrations," where he weaves together the cognitive and social factors of a discipline into an entertaining narrative on the influence of physicists and chemists in biology. Together these books enable us to understand the meteoric growth of molecular biology, the youngest and most controversial of the established scientific disciplines.

Individualism in Scientific Integration

Another important area of interdisciplinary interaction in the early twentieth century has been called the "evolutionary synthesis." It originated after the rediscovery of Mendel's laws of inheritance in 1900, when a fierce debate arose over the exact mechanism of evolution. One group favored Darwin's method of natural selection for species, whereby evolution developed in a very gradual manner. The other group preferred a macro-mutational approach, where new species could arise suddenly under the principles of Mendelian genetics. This genetic system was incompatible with Darwinism because the former was thought to pertain only to the inheritance of large variations. The gap between these groups was narrowed by biologists studying the genetics of simple organisms, who demonstrated that the genome (genetic character) actually consisted of a large array of genes that each accounted for only a small fraction of the organism's characteristics. This provided an opportunity for the population geneticists, well versed in the mathematics of statistical variation, to complete the synthesis by modelling the mutual influences of natural selection and genetic distribution in the species. Several fine studies of this synthesis have already appeared (Provine, 1971; Mayr and Provine, 1980; Mayr, 1982), but the area remains ripe for further studies of disciplinary interaction in science.

A milestone in the evolutionary synthesis was provided by Theodosius Dobzhansky's 1937 book on *Genetics and the Origin of Species*. Two essays in the book under review, by Lindley Darden and John Beatty, discuss the methodology and importance of Dobzhansky's contribution. In contrast to the earlier studies of biochemistry, where several disciplines contributed to the same research problem, these essays focus on the contribution of one scientist in the hope of discovering how individual research programs can fuse different disciplines.

Over a decade ago, Darden co-authored a groundbreaking paper in the philosophy of interdisciplinary science (Darden and Maull, 1977). It introduced the concept of "interfield theories," whereby a theory can bridge two fields by providing relationships between components in the fields. As Darden explains:

> Interfield theories function to solve problems that arise within a field but that cannot be solved with the techniques and concepts available in that field. The interfield theory serves as a bridge between two previously separate fields that may have been working on the same problem from different perspectives. Predictions may be made for both fields on the basis of the other; thus, the relation is reciprocal. By postulating a physical relation among entities or processes in two fields, interfield theories thus provide a kind of unity of science (in Bechtel, p. 120).

Darden has convincingly argued that interfield theories often provide a useful framework for understanding the integration of scientific disciplines. Based on this success it might be tempting to construct a naive interfield theory to explain the evolutionary synthesis, with genes as the entities which linked studies of evolution and inheritance. Darden, however, warns us against oversimplification, and instead suggests the development of a "synthetic theory." This new type of theory has "multi-field" influences, and differs from the interfield theory in that it not only provides links between existing fields but also postulates the need for development of a new field. Dobzhansky's unique contribution was therefore his development of a synthetic theory for evolution. In his text of 1937, he listed the hierarchical organization which acted as a foundation for the evolutionary synthesis: the level of genes and chromosomes, the level of the population, and the level of the species. In the new view, genes are part of chromosomes which make up organisms, and these constitute individual populations which in turn make up species. But in addition, Dobzhansky was unique in suggesting that a new field of research was needed, namely independent study at the species level to investigate isolating mechanisms involved in the formation of new species. It was by such conceptual organization on the theoretical level that the evolutionary synthesis was finally cemented.

I have devoted considerable discussion to Darden's essay in order to illustrate a common approach to understanding the nature of scientific disciplines, namely the construction of generalized theories that allow us to identify points of contact between fields. A problem with this technique is that it tends to focus on conceptual structure rather than scientific practice. Rather than discuss Dobzhansky's theorizing, Beatty's essay praises his thorough and extensive experimental research. This slant is characteristic of a new trend in the philosophy of science, which has prompted re-evaluation of the role of experimental research in the development of scientific thought. It has long been argued by philosophers that experimental observations serve only to test theories. By contrast, recent studies, pioneered by the sociology of Latour and Woolgar (1979) and the philosophy of Hacking (1983), have argued for the autonomy of experimentation and for a more realistic appraisal of the everyday activity of the scientist. Following this line of thought, Beatty praises Dobzhansky's integration of field and laboratory experiments which had previously been regarded as incommensurable. Dobzhansky's 1937 book, he claims, therefore offered more than a new conceptual hierarchy as proposed by Darden. Rather, it laid the foundation for the evolutionary synthesis by forging links between different regimes of scientific practice.

Allow me to offer a final bit of context — an interesting if somewhat cautionary complement to the above essays:

> Sharon Kingsland's exceptional study of population ecology, *Modeling Nature* (1985), shows the advantages of insight that can be obtained by humanizing scientific debates. Although not dealing with Dobzhansky specifically, she addresses a theme related to the discussion of interdisciplinarity in his work — the conceptual struggle between the mathematicians and the naturalists in the development of population ecology.
>
> The history of ecology is a history of changing criteria for imposing order on nature and resisting the alternative that all is really chaotic and contingent. Ecology is interesting not just for the answers it comes up with, for these are often temporary, but for the way the methods of imposing upon nature reflect changing times, changing moods, (p. 5)

Now, while it is often useful to examine disciplinary interaction in this way, as a conceptual matter, we should be careful to do so only within the constraints imposed by historical and sociological analysis. Consider, for example, how much has been written about the philosophy and intellectual history of twentieth century science, how the meaning of that writing is affected by whether it does or doesn't include the critical factor of geographic migration under the anti-Semitic aggressions of Nazi Germany? (Fleming, 1968)

Integrative Studies and Science

The main purpose of this review is to stimulate a wider interest in the study of interdisciplinary science. Although the subject matter may be unfamiliar, the underlying issues are ones which pervade all types of interdisciplinary enquiry. Consequently, not only can other conceptual viewpoints enhance the study of scientific disciplines, but the understanding of integrative studies as a whole can also benefit from a knowledge of scientific development. The quality and organisation of *Integrating Scientific Disciplines* makes it a fine introduction to the area, especially since it often contrasts different schools of thought. Although I have only treated a small portion of the book, the essays on biochemistry and the evolutionary synthesis point to the recurrence of a central theme: How can we meaningfully integrate the intellectual, practical, and social aspects of disciplinary interaction and development? This still remains the most challenging task facing the interdisciplinary scholar.

Biographical Note: Trace Jordan was born in England and received a B.Sc. and M.Sc. degree in Physics from the University of Essex. Pursuing an interest in the humanistic foundations of science he obtained an M.A. in History and Philosophy of Science from the University of Toronto, where his research covered the philosophical and historical foundations of interdisciplinary science. At present, he is in the graduate programs in Chemistry and Molecular Biophysics at Princeton University. Current research work involves both scientific and humanistic studies of the interactions between physics, chemistry, and biology: during the day he uses lasers to probe the dynamics of proteins, and at night he is developing a historical analysis of the interdisciplinary origins of molecular biology.

Bibliography

Appleman, P. (Ed.). (1979). *Darwin*. New York: W.W. Norton & Co.

Darden, L., & Maull, N. (1977). Interfield theories. *Philosophy of Science*, *44*, 43-64.

Fleming, D. (1968). Emigre physicists and the biological revolution. *Perspectives in American History*, *2*, 176-213.

Guerlac, H. (1976). Chemistry as a branch of physics: Laplace's collaboration with Lavoisier. *Historical Studies in the Physical Sciences, 7*, 393-276.

Hacking, I. (1983). *Representing and intervening*. Cambridge: Cambridge University Press.

Holmes, F.L. (1985). *Lavoisier and the chemistry of life*. Madison: University of Wisconsin Press.

Kingsland, S.E. (1985). *Modeling nature: episodes in the history of population genetics*. Chicago: University of Chicago Press.

Kohler, R.E. (1982). *From medicinal chemistry to biochemistry*. Cambridge: Cambridge University Press.

Kuhn, T.S. (1959). *The Copernican revolution*. Cambridge: Harvard University Press.

Kuhn, T.S. (1962). *The structure of scientific revolutions*. Chicago: Chicago University Press.

Latour, B., & Woolgar, S. (1979). *Laboratory life: the social construction of scientific facts*. Beverly Hills: Sage Publications.

Lemaine, G. (Ed.). *Perspectives on the emergence of scientific disciplines*. The Hague, Mouton & Co.

Mayr, E. (1982). *The growth of biological thought*. Cambridge: Harvard University Press.

Mayr, E., & Provine, W. (Eds.). (1980). *The evolutionary synthesis*. Cambridge: Harvard University Press.

Melhado, E.M. (1985). Chemistry, physics, and the chemical revolution. *ISIS, 76*, 195-211.

Olby, R. (1974). *The path to the double helix.* London: Macmillan.

Portugal, F.H., & Cohen, J.S. (1977). *A century of DNA*. Cambridge: MIT Press.

Provine, W. (1971). *The origin of theoretical population genetics*. Chicago: University of Chicago Press.