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ON AESTHETICS IN SCIENCE

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CONTENTS

PREFACE TO THE 1988 REISSUE

Nine years have passed since the first release of *On Aesthetics in Science*.

The course from which the idea for this volume developed has not been taught at MIT since my departure in 1978. But it has been rewarding to have continual positive response to the efforts made in the course and to this book.

Since the essays are concerned with issues that remain essential, we decided to reissue them as they appeared in the last printing without further revision.

In recent years there have been many new developments in physics, mathematics, biology, chemistry, and computer science which suggest fruitful topics for further aesthetic explorations. In a sequel to this book, I hope to explore some of these issues with the participation of scientists and those whose discipline is formally humanistic. (I still believe that much of the best work in science can be seen in a humanistic framework.)

New questions of aesthetics emerge around phenomena which will not obey the order we have been taught to perceive or to impose. We are forced to come to terms with the notion of a universe in inflationary movement, of patterns grounded in disorder and chaos—states that diverge from the traditional notions of aesthetics in science. What are the aesthetic corollaries to these new theories? How does the study of fractals or of string theory influence our sense of aesthetics? Does the attempt to incorporate new forms of scientific understanding shatter existing aesthetic assumptions? In a computer age, can intuition play the same role as it did for the physicists, chemists, and engineers in the first decades of this century?

In some ways these new discoveries and tools parallel developments in the visual arts, changing the older notions of the separation between order and disorder as well as between the rational and the irrational. The time has come to evaluate the meaning of beauty in aesthetic considerations of both science and art.

Fall, 1987 Judith Wechsler

INTRODUCTION

Aesthetic sensibility plays the part of the delicate sieve.
Henri Poincaré

Scientists talking about their own work and that of other scientists use the terms "beauty," "elegance," and "economy" with the euphoria of praise more characteristically applied to painting, music, and poetry. Or there is the exclamation of recognition—the "Aha" that accompanies the discovery of a connection or an unexpected but utterly right realization in art and science. These are epithets of the sense of "fit"—of finding the most appropriate, evocative and correspondent expression for a reality heretofore unarticulated and unperceived, but strongly sensed and actively probed. The right formalism or model which "captures" this reality seems almost magical in its potency. Both art and science evoke the previously ineffable in making ideas and concepts clear, cogent, and manipulable.

Heisenberg recalls commenting to Einstein on the force of recognition he associates with aesthetic experience:

> You may object that by speaking of simplicity and beauty I am introducing aesthetic criteria of truth, and I frankly admit that I am strongly attracted by the simplicity and beauty of the mathematical schemes which nature presents us. You must have felt this too: the almost frightening simplicity and wholeness of the relationship, which nature suddenly spreads out before us. . . .[1]

Definition

But the role of aesthetic judgment is rarely mentioned in the corpus of science and mathematics. When scientists, however, reflect on their work, the development of concepts, and the theories that expound them, it is evident that intuition and aesthetics guide their sense of "this is how it has to be," their sense of rightness.

It is almost too obvious to say that if one believes science to have a singular and exclusive relation to reality and assume it to be synonymous with truth, then the idea of aesthetics in scientific judgment or cognition may seem capricious or marginal. One can still regard the products of science as beautiful (truth equals beauty). But if one views science as attempting to approximate reality, subject to experiment but not necessarily to verification, then there is latitude, and one can conceive that the choice of alternative hypotheses are subject to aesthetic factors. Karl

Popper's theory that "not the *verifiability* but the falsifiability of a system be taken as a criteria of demarcation," allows for that latitude. ". . . it must be possible for an empirical scientific system to be refuted by experience," he writes in *The Logic of Scientific Discovery* (1959).

The Oxford English Dictionary defines aesthetics as "things perceptible to the senses, things material" as opposed to "things thinkable or immaterial." Aesthetics by this definition might seem inapplicable to those areas of science whose operations appear to be purely intellectual-logical processes, mathematical formalisms.

Kant understood the limitations of such a definition when he commented in *The Critique of Pure Reason*, "concepts without factual content are empty; sense-data without concepts are blind. The senses cannot think. The understanding cannot see. By their union only can knowledge be produced."

In its dealings with "things perceptible to the senses," aesthetics comes to grips with *relations:* structure, context, schemata, similarity/dissimilarity, consonance/dissonance. (About isolated, simple sense impressions aesthetics has little to say.) These relations, which are sometimes separated from their "factual content" or perceptual substrate in science, are still subject to aesthetic preference, as they are in art or nature where this separation has not been made.

In this sense, Kant writes, aesthetics is "the science which treats the *conditions* of sensuous perception" (my emphasis).

A dichotomy exists in science between those like Bohr who assume that their starting point and base of verification is sense perception, and those, like Heisenberg, who believe that sense perception is an unnecessary limitation. Such a case is the contrast between Hertz and Mach: Hertz advocated a purely intellectual process in his "pure natural science," while Mach believed "every statement in physics has to state relations between observable quantities." Both pure science and science related to observation are subject to aesthetic judgment. The aesthetics of pure relations engages our minds as music does through harmonic relationships.

Intuition as well as aesthetic judgments operate in both approaches to science. In art, and in life, we acknowledge the place of aesthetics and intuition, but we don't readily associate these more tacit dimensions with the logical processes of science. Yet, as Norbert Wiener and Arturo Rosenblueth observe,

> An intuitive flair for what will turn out to be the most important general question gives a basis for selecting some of the significant among the indefinite number of trivial experiments which could be carried out at that stage. Quite vague and tacit generalizations thus influence the selection of data at the start.[2]

Scope

The contributors to this book all maintain that aesthetics is a crucial factor in the scientific process. Aesthetics is discussed in this collection not as a systematic discipline in philosophy, but as a mode of discrimination and response—a guideline for the *appropriateness* of a scientific expression (as in the chapters by Papert and Vickers).

Aesthetics is also associated with visualization (Miller), structure (Smith), metaphor, image, and analogy (Morrison, Gruber). The question is raised, How do aesthetic considerations affect the form, development, and efficacy of models?

Aesthetic sensibility also enters the appreciative mode. For the majority of practicing scientists, aesthetic criteria enter in the ways of response. The aesthetics of recognition is at work when we grasp an idea, understand how a principle operates, or how a solution was found. (This issue is discussed in all the essays.) Our admiration of Copernicus or Newton is of this order and can be likened to our aesthetic appreciation of Cézanne, Bach, or Milton. Science too can be a source of aesthetic delight.

As in art, aesthetics is subject to period styles as well as personal ones. It is bound to change in time, in both subject and locus. There is ample evidence to suggest changes in scientific style and taste, in the problems posed and the methods posited. While a sense of "fit" may be timeless, the context and connections in which a theory first emerges are affected by schemata and tradition. In the twentieth century, aesthetics as the appreciation of form has expanded to include process as well as product.

Process

The emphasis in this book is on process in science, the issue of modeling. The finished work, in science as in art, gives evidence of its process. However, the balance between product and process differ in art and science. In art, it is the finished painting, sonnet, or sonata which is normally the subject of our criticism or appreciation. Science doesn't exhibit products for aesthetic criticism in this way; there is hardly any recognized vocabulary of aesthetic criticism and response for science. The usual criterion for "success" of a scientific product—an equation, a physical model, or a written paper—is whether it works, that is, predicts, explains. Aesthetic judgments operate in the cognitive processes of arriving at that product.

Our contemporary interest in process has a history. At the end of the nineteenth century, developments occurred in the arts and sciences which challenged the belief in an objective reality unmediated by the subjective perceiver. In painting, the breakdown of "scientific" perspective meant an end to an established a priori way of translating reality onto a two-dimensional surface. Cézanne asserted subjective perception in the form of shifting perspectives. Similarly in literature, James Joyce composed his novels from the multiple view points of his characters.

It is in this period that science too began to recognize the individual, perceptual and intellectual screen in constructing models of reality, for example, in Poincaré's advocacy of intuition and Einstein's theory of relativity. These developments in the arts and sciences articulated the complex phenomenological relationship of subjective perceiver and objective reality.

Now more than ever we focus on the effect of process in art and science; our age is particularly self-conscious of cognitive modes. Because of Freud we are alert to latent as well as manifest content. The studies of Piaget, Bruner, and other cognitive psychologists indicate the role models play in our thinking. Systems analysis and conceptual art further prepare us to look at process rather than product.

Scientist's predilections are often revealed in their choices of imagery and metaphor. Niels Bohr, recalled Heisenberg, equates the language of poetry and physics:

> . . . when it comes to atoms, language can be used only as in poetry. The poet too is not nearly so concerned with describing facts as with creating images and establishing mental connections. . . . Quantum theory . . . provides us with a striking illustration of the fact that we can fully understand a connection though we can only speak of it in images and parables . . .[3]

Aesthetics viewed as a mode of scientific cognition may parallel a scientist's outlook and concern in other areas of life. Poincaré observed of mathematicians, "It is the the very nature of their mind which makes them logicians or intuitionalists, and they cannot lay it aside when they approach a new subject."[4] Werner Heisenberg and Niels Bohr often wrote of these links. Gerald Holton has examined the mapping of personal life onto science in Einstein's work.[5]

Intuition and Aesthetics

Bohr, Dirac, Einstein, Heisenberg, Poincaré, and others acknowledge intuitive and aesthetic judgment as decisive factors in the acceptance or rejection of a particular model.

Poincaré was convinced of the role of intuition in scientific process.

> Pure logic could never lead us to anything but tautologies; it could create nothing new; not from it alone can any science issue. In one sense these philosophers are right; to make arithmetic, as to make geometry, or to make any science, something else than pure logic is necessary. To designate this something else we have no word other than *intuition*.[6]

Poincaré goes further, linking intuition with aesthetics:

> It may appear surprising that sensibility should be introduced in connection with mathematical demonstrations, which, it would seem, can only interest the intellect. But not if we bear in mind the feeling of mathematical beauty, of the harmony of numbers and forms and of geometric elegance. It's a real aesthetic feeling that all mathematicians recognize, and this is truly sensibility . . . The useful combinations are precisely the most beautiful . . .[7]

Reinforcing Poincaré's trust of aesthetic judgment, Dirac commented on Schrödinger's not publishing his first version of the wave equation because it conflicted with empirical data:

> I think there is a moral to this story, namely that it is more important to have beauty in one's equations than to have them fit experiment. . . . It seems that if one is working from the point of view of getting beauty in one's equations, and if one has really a sound insight, one is on a sure line of progress. If there is not complete agreement between the results of one's work and experiment, one should not allow oneself to be too discouraged, because the discrepancy may well be due to minor features that are not properly taken into account and that will get cleared up with further developments of the theory.[8]

Polarities

Dirac and Poincaré both appeal to aesthetic criteria yet the frame of their aesthetic differs. Poincaré's is a more geometric sensibility, Dirac's an abstract mode of deductive reasoning. But Dirac too is concerned with the beauty of form, of relativistic covariance or persistence of form. The capacity to visualize, Dirac maintains, does not advance new theories, but rather reflects a more basic need to picture and represent.

Many scientists have commented on the polarities, even the dialectic, of scientific imagination. Gerald Holton has described this phenomenon as the "thema and antithema" of science. Two basic forms of scientific thinking have been characterized as descriptive vs. structural science (Aristotle vs. Plato), "the concept of space vs. the concept of number" (Ernst Cassirer), pictorial models (process of operations) vs. functional models (functional mapping) (Wiener), logicians and analysts vs. intuitionalists and geometers (Poincaré).

Contrasting modes of scientific imagination is a recurrent issue in this book. Vickers distinguishes between aesthetic criteria and rational deduction in making judgments, Papert between intuition and pure logic in mathematics, Miller between visualization and nonvisualization in quantum theory, and Gruber between classic and romantic imagery in nineteenth century biology.

We know from the development of quantum theory that alternative explanations can coexist, be complementary: wave and particle, continuity and discontinuity, mathematical formalism and visualization, each of which "describes" the nature of atomic phenomena. (Both are needed because neither saves *all* the phenomena.)

It may be more difficult to specify the aesthetic properties of symbolic mathematical relations than those of models, metaphors, and images based on our experience and observation.

The aesthetics of pure mathematical relations and the strong emotion it evokes recall the formalist aesthetic in art—though at a more abstract level—since mathematical formulations sometimes eschew visualization. The principal criterion in this aesthetic was termed "significant form" by the art theorists Clive Bell and Roger Fry around 1914. Significant form implies the optimal unity and coherence of the compositional elements. Fry's position marked the beginning of the modernist aesthetic in art, with its lack of concern for representation and its focus on the beauty of formal relations. Significant form evokes a particular kind of reaction that Fry described as "aesthetic emotion," which, according to him, is more intense and focused than the ordinary emotion we experience in our daily lives. Mathematicians have said the same of their experience of pure mathematical relations.

Conclusion

The choice of orientation is not necessarily set in science by the problem but by a mode of thinking. Though there are constraints, there is no a priori essential epistemological way of seeing. Therefore the role of cognitive mode and aesthetic sensibility plays a vital part in the structure and style of the scientific process.

In summary, aesthetics is presented in this collection as a mode of cognition which focuses on forms and metaphors used in scientific conceptualizing and modeling. The attention to process in science and art leads to a consideration of the part played by paradigms (Kuhn) and personal style in discovery and invention.

Viewed as a way of knowing, aesthetics in science is concerned with the metaphorical and analogical relationship between reality and concepts, theories and models. The search in science for models that illuminate nature seems to parallel certain crucial processes in art, as Cyril Smith points out: they share a fundamental evocative quality.

The forms of symbolization are central to the study of aesthetics in science. Science uses a symbolic language, most commonly mathematics. New concepts necessarily expand the vocabulary and syntax of this language. The way new symbolic forms develop is in part influenced by aesthetic concerns.

Scientific ideas (models, hypotheses) develop within a cultural framework rooted in the scientist's time in history. There are cultural styles and traditions in scientific concepts. Though there has been a historically recurrent appreciation of elegance and economy, Victorian science, for example, often preferred more complicated formulations. An examination of aesthetic criteria reveals the pressure of value systems that are related to the scientist's social and cultural context. The ability to relinquish the predictability of classical physics and accept indeterminacy, probability, and complementarity, we associate with contemporary sensibility. So too the emphasis on process over product.

This book examines the aesthetics of formulae, theories, concepts, models, and processes. The aesthetic factors in cognition—manifest in both art and science, though until recently more recognizable in art—are continuous and broader than either. The essays by four scientists and two social scientists will hopefully enrich the reader's view of the nature of aesthetic cognition in the scientific process.

Notes

1. Werner Heisenberg, *Physics and Beyond* (New York: Harper & Row, 1971), p. 68.
2. Arturo Rosenblueth and Norbert Wiener, "Roles of Models in Science," *Philosophy of Science*, XX (1945): 317.
3. Heisenberg, *Physics and Beyond*, p. 210.
4. Henri Poincaré, *The Value of Science*, trans. G. B. Halstead (New York: Dover Publications, 1958), p. 15. (Originally published in 1905.)
5. Gerald Holton, "Mach, Einstein, and the Search for Reality," *Thematic Origins of Scientific Thought: Kepler to Einstein* (Cambridge: Harvard University Press, 1973).
6. Poincaré, *The Value of Science*, p. 19.
7. Henri Poincaré, *Science and Method*, trans. Maitland (New York: Dover Publications, n. d.), p. 59. (Originally published in 1908.)
8. P. A. M. Dirac, "The Evolution of the Physicist's Picture of Nature," *Scientific American*, May 1963, p. 47.