several chapters by enriching them with new examples or pertinent observations.

I sincerely believe that this edition, more than the others, merits the unusual attention it has received from the new generation, along with the endorsement of certain illustrious scientists, for whose good will I am grateful.

Madrid, December 6, 1916

Advice for a Young Investigator

1 Introduction

Thoughts about general methods. Abstract rules are sterile. Need to enlighten the mind and strengthen resolve. Organization of the book

I shall assume that the reader's general education and background in philosophy are sufficient to understand that the major sources of knowledge include observation, experiment, and reasoning by induction and deduction.

Instead of elaborating on accepted principles, let us simply point out that for the last hundred years the natural sciences have abandoned completely the Aristotelian principles of intuition, inspiration, and dogmatism.

The unique method of reflection indulged in by the Pythagoreans and followers of Plato (and pursued in modern times by Descartes, Fichte, Krause, Hegel, and more recently at least partly by Bergson) involves exploring one's own mind or soul to discover universal laws and solutions to the great secrets of life. Today this approach can only generate feelings of sorrow and compassion—the latter because of talent wasted in the pursuit of chimeras, and the former because of all the time and work so pitifully squandered.

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The history of civilization proves beyond doubt just how sterile the repeated attempts of metaphysics to guess at nature's laws have been. Instead, there is every reason to believe that when the human intellect ignores reality and concentrates within, it can no longer explain the simplest inner workings of life's machinery or of the world around us.

The intellect is presented with phenomena marching in review before the sensory organs. It can be truly useful and productive only when limiting itself to the modest tasks of observation, description, and comparison, and of classification that is based on analogies and differences. A knowledge of underlying causes and empirical laws will then come slowly through the use of inductive methods. Another commonplace worth repeating is that science cannot hope to solve Ultimate Causes. In other words, science can never understand the foundation hidden below the appearance of phenomena in the universe. As Claude Bernard has pointed out, researchers cannot transcend the determinism of phenomena; instead, their mission is limited to demonstrating the *how,* never the *why,* of observed changes. This is a modest goal in the eyes of philosophy, yet an imposing challenge in actual practice. Knowing the conditions under which a phenomenon occurs allows us to reproduce or eliminate it at will, therefore allowing us to control and use it for the benefit of humanity. Foresight and action are the advantages we obtain from a deterministic view of phenomena.

The severe constraints imposed by determinism may appear to limit philosophy in a rather arbitrary way.[1] However, there is no denying that in the natural sciences—and especially in biology—it is a very effective tool for avoiding the innate tendency to explain the universe as a whole in terms of general laws. They are are like a germ with all the neces-

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sary parts, just as a seed contains all the potentialities of the future tree within it. Now and then philosophers invade the field of biological sciences with these beguiling generalizations, which tend to be unproductive, purely verbal solutions lacking in substance. At best, they may prove useful when viewed simply as working hypotheses.

Thus, we are forced to concede that the "great enigmas" of the universe listed by Du Bois-Raymond are beyond our understanding at the present time. The great German physiologist pointed out that we must resign ourselves to the state of *ignoramus,* or even the inexorable *ignorabimus.*

There is no doubt that the human mind is fundamentally incapable of solving these formidable problems (the origin of life, nature of matter, origin of movement, and appearance of consciousness). Our brain is an organ of action that is directed toward practical tasks; it does not appear to have been built for discovering the ultimate causes of things, but rather for determining their immediate causes and invariant relationships. And whereas this may appear to be very little, it is in fact a great deal. Having been granted the immense advantage of participating in the unfolding of our world, and of modifying it to life's advantage, we may proceed quite nicely without knowing the essence of things.

It would not be wise in discussing general principles of research to overlook those panaceas of scientific method so highly recommended by Claude Bernard, which are to be found in Bacon's *Novum Organum* and Descartes's *Book of Methods.* They are exceptionally good at stimulating thought, but are much less effective in teaching one how to discover. After confessing that reading them may suggest a fruitful idea or two, I must further confess an inclination to share De Maistre's view of the *Novum Organum:* "Those who have made the greatest discoveries in science never read it,

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and Bacon himself failed to make a single discovery based on his own rules." Liebig appears even more harsh in his celebrated *Academic Discourse* when he states that Bacon was a scientific dilettante whose writings contain nothing of the processes leading to discovery, regardless of inflated praise from jurists, historians, and others far removed from science.

No one fails to use instinctively the following general principles of Descartes when approaching any difficult problem: "Do not acknowledge as true anything that is not obvious, divide a problem into as many parts as necessary to attack it in the best way, and start an analysis by examining the simplest and most easily understood parts before ascending gradually to an understanding of the most complex." The merit of the French philosopher is not based on his application of these principles but rather on having formulated them clearly and rigorously after having profited by them unconsciously, like everyone else, in his thinking about philosophy and geometry.

I believe that the slight advantage gained from reading such work, and in general any work concerned with philosophical methods of investigation, is based on the vague, general nature of the rules they express. In other words, when they are not simply empty formulas they become formal expressions of the mechanism of understanding used during the process of research. This mechanism acts unconsciously in every well-organized and cultivated mind, and when the philosopher reflexly formulates psychological principles, neither the author nor the reader can improve their respective abilities for scientific investigation. Those writing on logical methods impress me in the same way as would a speaker attempting to improve his eloquence by learning about brain speech centers, about voice mechanics,

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and about the distribution of nerves to the larynx—as if knowing these anatomical and physiological details would create organization where none exists, or refine what we already have.[2]

It is important to note that the most brilliant discoveries have not relied on a formal knowledge of logic. Instead, their discoverers have had an acute inner logic that generates ideas with the same unstudied unconsciousness that allowed Jourdain to create prose. Reading the work of the great scientific pioneers such as Galileo, Kepler, Newton, Lavoisier, Geoffroy Saint-Hilaire, Faraday, Ampere, Bernard, Pasteur, Virchow, and Liebig is considerably more effective. However, it is important to realize that if we lack even a spark of the splendid light that shone in those minds, and at least a trace of the noble zeal that motivated such distinguished individuals, this exercise may if nothing else convert us to enthusiastic or insightful commentators on their work—perhaps even to good scientific writers—but it will not create the spirit of investigation within us.

A knowledge of principles governing the historical unfolding of science also provides no great advantage in understanding the process of research. Herbert Spencer proposed that intellectual progress emerges from that which is homogeneous and that which is heterogeneous, and by virtue of the *instability of that which is homogeneous*, and of the principle that *every cause produces more than one effect*, each discovery immediately stimulates many other discoveries. However, even if this concept allows us to appreciate the historical march of science, it cannot provide us with the key to its revelations. The important thing is to discover how each investigator, in his own special domain, was able to segregate heterogeneous from homogeneous, and to learn

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