The Experiment As Mediator between Object and Subject

As the human being becomes aware of objects in his environment he will relate them to himself, and rightly so since his fate hinges on whether these objects please or displease him, attract or repel him, help or harm him. This natural way of seeing and judging things seems as easy as it is essential, although it can lead to a thousand errors—often the source of humiliation and bitterness in our life.

A far more difficult task arises when a person's thirst for knowledge kindles in him a desire to view nature's objects in their own right and in relation to one another. On the one hand he loses the yardstick which came to his aid when he looked at things from the human standpoint; i.e., in relation to himself. This yardstick of pleasure and displeasure, attraction and repulsion, help and harm, he must now renounce absolutely; as a neutral, seemingly godlike being he must seek out and examine what is, not what pleases. Thus the true botanist must remain unmoved by beauty or utility in a plant; he must explore its formation, its relation to other plants. Like the sun which draws forth every plant and shines on all, he must look upon each plant with the same quiet gaze; he must find the measure for what he learns, the data for judgment, not in himself but in the sphere of what he observes.

The history of science teaches us how difficult this renunciation is for man. The second part of our short essay will discuss how he thus arrives (and must arrive) at hypotheses, theories, systems, any of the modes of perception which help in our effort to grasp the infinite; the first part of the essay will deal with how man sets about recognizing the forces of nature. Recently I have been studying the history of physics[1] and this point arose frequently—hence the present brief discourse, an attempt to outline in general how the study of nature has been helped or hindered by the work of able scientists.

We may look at an object in its own context and the context of other objects, while refraining from any immediate response of desire or dislike. The calm exercise of our powers of attention will quickly lead us to a rather clear concept of the object, its parts, and its relationships;

the more we pursue this study, discovering further relations among things, the more we will exercise our innate gift of observation. Those who understand how to apply this knowledge to their own affairs in a practical way are rightly deemed clever. It is not hard for any well-organized person, moderate by nature or force of circumstance, to be clever, for life corrects us at every step. But if the observer is called upon to apply this keen power of judgment to exploring the hidden relationships in nature, if he is to find his own way in a world where he is seemingly alone, if he is to avoid hasty conclusions and keep a steady eye on the goal while noting every helpful or harmful circumstance along the way, if he must be his own sharpest critic where no one else can test his work with ease, if he must question himself continually even when most enthusiastic—it is easy to see how harsh these demands are and how little hope there is of seeing them fully satisfied in ourselves or others. Yet these difficulties, this hypothetical impossibility, must not deter us from doing what we can. At any rate, our best approach is to recall how able men have advanced the sciences, and to be candid about the false paths down which they have strayed,[2] only to be followed by numerous disciples, often for centuries, until later empirical evidence could bring researchers back to the right road.

It is undeniable that in the science now under discussion, as in every human enterprise, empirical evidence carries (and should carry) the greatest weight. Neither can we deny the high and seemingly creative independent power found in the inner faculties through which the evidence is grasped, collected, ordered, and developed. But how to gather and use empirical evidence, how to develop and apply our powers—this is not so generally recognized or appreciated.

We might well be surprised how many people are capable of sharp observation in the strictest sense of the word. When we draw their attention to objects, we will discover that such people enjoy making observations, and show great skill at it. Since taking up my study of light and color I have often had opportunity to appreciate this. Now and then I discuss my current interests with people unacquainted with the subject: once their attention is awakened they frequently make quick note of phenomena I was unaware of or had neglected to observe. Thus they may be able to correct ideas developed in haste, and even produce a breakthrough by transcending the inhibitions in which exacting research often traps us.

Thus what applies in so many other human enterprises is also true here: the interest of many focused on a single point can produce excellent results. Here it becomes obvious that the researcher will meet his downfall if he has any feeling of envy which seeks to deprive others of the discoverer's laurels, any overwhelming desire to deal alone and arbitrarily with a discovery.

I have always found the cooperative method of working satisfactory, and I intend to continue with it. I am aware of the debts I have incurred along the way, and it will give me great pleasure later to acknowledge these publicly.

If man's natural talent for observation can be of such help to us, how much more effective must it be when trained observers work hand in hand. In and of itself, a science is sufficient to support the work of many people, although no one person can carry an entire science. We may note that knowledge, like contained but living water, rises gradually to a certain level, and that the greatest discoveries are made not so much by men as by the age; important advances are often made by two or more skilled thinkers at the same time. We have already found that we owe much to the community and our friends; now we discover our debt to the world and the age we live in. In neither case can we appreciate fully enough our need for communication, assistance, admonition, and contradiction to hold us to the right path and help us along it.

Thus in scientific matters we must do the reverse of what is done in art. An artist should never present a work to the public before it is finished because it is difficult for others to advise or help him with its production. Once it is finished, however, he must consider criticism or praise, take it to heart, make it a part of his own experience, and thereby develop and prepare himself for new works. In science, on the other hand, it is useful to publish every bit of empirical evidence, even every conjecture; indeed, no scientific edifice should be built until the plan and materials of its structure have been widely known, judged and sifted.

I will now turn to a point deserving of attention; namely, the method which enables us to work most effectively and surely.

When we intentionally reproduce empirical evidence found by earlier researchers, contemporaries, or ourselves, when we re-create natural or artificial phenomena, we speak of this as an experiment.

The main value of an experiment lies in the fact that, simple or compound, it can be reproduced at any time given the requisite preparations, apparatus, and skill. After assembling the necessary materials we may perform the experiment as often as we wish. We will rightly marvel at human ingenuity when we consider even briefly the variety of arrangements and instruments invented for this purpose. In fact, we can note that such instruments are still being invented daily.

As worthwhile as each individual experiment may be, it receives its real value only when united or combined with other experiments. However, to unite or combine just two somewhat similar experiments calls for more rigor and care than even the sharpest observer usually expects of himself. Two phenomena may be related, but not nearly so

closely as we think. Although one experiment seems to follow from another, an extensive series of experiments might be required to put the two into an order actually conforming to nature.

Thus we can never be too careful in our efforts to avoid drawing hasty conclusions from experiments or using them directly as proof to bear out some theory. For here at this pass, this transition from empirical evidence to judgment, cognition to application, all the inner enemies of man lie in wait: imagination, which sweeps him away on its wings before he knows his feet have left the ground; impatience; haste; self-satisfaction; rigidity; formalistic thought; prejudice; ease; frivolity; fickleness—this whole throng and its retinue. Here they lie in ambush and surprise not only the active observer but also the contemplative one who appears safe from all passion.

I will present a paradox of sorts as a way of alerting the reader to this danger, far greater and closer at hand than we might think. I would venture to say that we cannot prove anything by one experiment or even several experiments together, that nothing is more dangerous than the desire to prove some thesis directly through experiments, that the greatest errors have arisen just where the dangers and shortcomings in this method have been overlooked. I will explain this assertion more clearly lest I merely seem intent on raising a host of doubts. Every piece of empirical evidence we find, every experiment in which this evidence is repeated, really represents just one part of what we know. Through frequent repetition we attain certainty about this isolated piece of knowledge. We may be aware of two pieces of empirical evidence in the same area; although closely related, they may seem even more so, for we will tend to view them as more connected than they really are. This is an inherent part of man's nature; the history of human understanding offers thousands of examples of this, and I myself make this error almost daily.

This mistake is associated with another which often lies at its root. Man takes more pleasure in the idea than in the thing; or rather, man takes pleasure in a thing only insofar as he has an idea of it. The thing must fit his character, and no matter how exalted his way of thinking, no matter how refined, it often remains just a way of thinking, an attempt to bring several objects into an intelligible relationship which, strictly speaking, they do not have. Thus the tendency to hypotheses, theories, terminologies, and systems, a tendency altogether understandable since it springs by necessity from the organization of our being.

Every piece of empirical evidence, every experiment, must be viewed as isolated, yet the human faculty of thought forcibly strives to unite all external objects known to it. It is easy to see the risk we run when we try to connect a single bit of evidence with an idea already formed, or use individual experiments to prove some relationship not fully perceptible to the senses but expressed through the creative power of the mind.

Such efforts generally give rise to theories and systems which are a tribute to their author's intelligence. But with undue applause or protracted support they soon begin to hinder and harm the very progress of the human mind they had earlier assisted.

We often find that the more limited the data, the more artful a gifted thinker will become.[3] As though to assert his sovereignty he chooses a few agreeable favorites from the limited number of facts and skillfully marshals the rest so they never contradict him directly. Finally he is able to confuse, entangle, or push aside the opposing facts and reduce the whole to something more like the court of a despot than a freely constituted republic.

So deserving a man will not lack admirers and disciples who study this fabric of thought[4] historically, praise it, and seek to think as much like their master as possible. Often such a doctrine becomes so widespread that anyone bold enough to doubt it would be considered brash and impertinent. Only in later centuries would anyone venture to approach such a holy relic, apply common sense to the subject, and—taking a lighter view—apply to the founder of the sect what a wag once said of a renowned scientist: "He would have been a great man if only he hadn't invented so much."

It is not enough to note this danger and warn against it. We need to declare our own views by showing how we ourselves would hope to avoid this pitfall, or by telling what we know of how some predecessor avoided it.

Earlier I stated my belief that the direct use of an experiment to prove some hypothesis is detrimental; this implies that I consider its indirect use beneficial. Here we have a pivotal point, one requiring clarification.

Nothing happens in living nature that does not bear some relation to the whole. The empirical evidence may seem quite isolated, we may view our experiments as mere isolated facts, but this is not to say that they are, in fact, isolated. The question is: how can we find the connection between these phenomena, these events?

Earlier we found those thinkers most prone to error who seek to incorporate an isolated fact directly into their thinking and judgment. By contrast, we will find that the greatest accomplishments come from those who never tire in exploring and working out every possible aspect and modification of every bit of empirical evidence, every experiment.

It would require a second essay to describe how our intellect can help us with this task; here we will merely indicate the following. All things in nature, especially the commoner forces and elements, work incessantly upon one another; we can say that each phenomenon is

connected with countless others just as we can say that a point of light floating in space sends its rays in all directions. Thus when we have done an experiment of this type, found this or that piece of empirical evidence, we can never be careful enough in studying what lies next to it or derives directly from it. This investigation should concern us more than the discovery of what is related to it. To follow every single experiment through its variations is the real task of the scientific researcher. His duty is precisely the opposite of what we expect from the author who writes to entertain. The latter will bore his readers if he does not leave something to the imagination, while the former must always work as if he wished to leave nothing for his successors to do. Of course, the disproportion between our intellect and the nature of things will soon remind us that no one has gifts enough to exhaust the study of any subject.

In the first two parts of my *Contributions to Optics*[5] I sought to set up a series of contiguous experiments derived from one another in this way. Studied thoroughly and understood as a whole, these experiments could even be thought of as representing a single experiment, a single piece of empirical evidence explored in its most manifold variations.

Such a piece of empirical evidence, composed of many others, is clearly of a higher sort. It shows the general formula, so to speak, that overarches an array of individual arithmetic sums. In my view, it is the task of the scientific researcher to work toward empirical evidence of this higher sort—and the example of the best men in the field supports this view. From the mathematician we must learn the meticulous care required to connect things in unbroken succession, or rather, to derive things step by step. Even where we do not venture to apply mathematics we must always work as though we had to satisfy the strictest of geometricians.

In the mathematical method we find an approach which by its deliberate and pure nature instantly exposes every leap in an assertion. Actually, its proofs merely state in a detailed way that what is presented as connected was already there in each of the parts and as a consecutive whole, that it has been reviewed in its entirety and found to be correct and irrefutable under all circumstances. Thus its demonstrations are always more exposition, recapitulation, than argument. Having made this distinction, I may now return to something mentioned earlier.

We can see the great difference between a mathematical demonstration which traces the basic elements through their many points of connection, and the proof offered in the arguments of a clever speaker. Although arguments may deal with utterly separate matters, wit and imagination can group them around a single point to create a surprising semblance of right and wrong, true and false. It is likewise possible to support a hypothesis or theory by arranging individual experiments like arguments and offering proofs which bedazzle us to some degree.

But those who wish to be honest with themselves and others will try by careful development of individual experiments to evolve empirical evidence of the higher sort. These pieces of evidence may be expressed in concise axioms and set side by side, and as more of them emerge they may be ordered and related. Like mathematical axioms they will remain unshakable either singly or as a whole. Anyone may examine and test the elements, the many individual experiments, which constitute this higher sort of evidence; it will be easy to judge whether we can express these many components in a general axiom, for nothing here is arbitrary.

The other method which tries to prove assertions by using isolated experiments like arguments often reaches its conclusions furtively or leaves them completely in doubt. Once sequential evidence of the higher sort is assembled, however, our intellect, imagination and wit can work upon it as they will; no harm will be done, and, indeed, a useful purpose will be served. We cannot exercise enough care, diligence, strictness, even pedantry, in collecting basic empirical evidence; here we labor for the world and the future. But these materials must be ordered and shown in sequence, not arranged in some hypothetical way nor made to serve the dictates of some system. Everyone will then be free to connect them in his own way, to form them into a whole which brings some measure of delight and comfort to the human mind. This approach keeps separate what must be kept separate; it enables us to increase the body of evidence much more quickly and cleanly than the method which forces us to cast aside later experiments like bricks brought to a finished building.

The views and examples of the best men give me reason to hope that this is the right path, and I trust my explanation will satisfy those of my friends who ask from time to time what I am really seeking to accomplish with my optical experiments. My intention is to collect all the empirical evidence in this area, do every experiment myself, and develop the experiments in their most manifold variations so that they become easy to reproduce and more accessible. I will then attempt to establish the axioms in which the empirical evidence of a higher nature can be expressed, and see if these can be subsumed under still higher principles. If imagination and wit sometimes run impatiently ahead on this path, the method itself will fix the bounds to which they must return.

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