AN EPISTEMOLOGICAL INQUIRY OF SCIENTIFIC PRACTICE

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Abstract: This study explores some theoretical issues in scientific research such as, the nature of experimentation and problems of methodology in scientific practice as well as the question of truth, rationality, objectivity and utility of scientific discoveries. The paper discusses a number of theorizing that have emerged in response to the challenge raised by the above concerns. Epistemological models of science from critical rationalists, like Popper, Kuhn, Feyerabend and the neo-pragmatic methodological orientation of Arthur Fine's Natural Ontological Attitude (NOA) to Science, have been adopted as points of discussion on what science as an empirical discipline entail. The paper concludes that a rigorous epistemological discussion on the methodology of scientific inquiry is a desideratum for the progress of science.

Keywords: Scientific Knowledge, Experimentation, Objectivity, Truth, Falsifiability, Natural Ontological Attitude (NOA), Normal Science, Anarchism.

Introduction

If the epistemological concerns about the methodologies of scientific inquiry were defined by a mere description of scientific practice, especially when research is conducted, then the issue would have been easy to address. However, this is clearly not the case. A major reason the problem of scientific methodology has remained contentious till today is the nature of the problem of science itself. It is not gainsaid that scientific research involves a laborious process. As a result, any attempt to systematically demonstrate its procedures of inquiry cannot be a minor task. Moreover, the methods of scientific inquiry cannot be well construed by solely describing the activities of scientists because any form of description must itself be selective, and hence, cannot furnish the whole image of what is described. When philosophy interrogates the basic tenets of science, epistemological, ontological as well as normative issues ensues, which overshadows the conditions of mere descriptive exercises.

This paper raises some epistemological issues involved in the practices and methodologies of scientific research. Tellingly, critical appraisals of how and why science operates have implications to the manner in which scientists should conduct their research if their enterprise is to thrive. In this work, we shall expound some of the inherent attributes of scientific research and discuss a few methodological perspectives to the nature of truth and objectivity in science, all of which have surfaced from the rigorous philosophical inquiry on the heuristic nature of the subject.

What the Method of Scientific Inquiry Entails

Articulating the constituents and procedures of scientific methodology is oftentimes a daunting task. This is particularly so, because the possible objects of scientific knowledge are not *in situ* spelled out. As Cornelius Benjamin rightly points out "one cannot say before science has begun what the possible objects of science are, for one can know whether an object is scientific only by trying to know it scientifically".[1] However, we can make an attempt at conceptualizing the matter at hand. So construed, scientific method is an experimental process of knowledge acquisition which entails painstaking and rigorous observation; formulating hypothesis based on such observations through inductive process; testing and measuring of deductions drawn from the hypothesis, and refinement of the hypothesis based on the experimental findings.[2] Stated otherwise, the process of scientific methodology entails making hypothesis, deducing predictions from them as logical derivatives and then follow through with experimental observations based on the prediction made.

There is an expansive belief that scientific research begins with observation. Perhaps, this belief is a natural one since science as an empirical discipline is expected to explicate phenomena as it occurs around us. This sentiment has however, come under severe criticism ever since Immanuel Kant's Critique of Pure Reason (1781) was published. Scientists have now come to

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[1] Cornelius Benjamin, An Introduction to the Philosophy of Science, New York: The Macmillan Company, 1937),3.

[2] See Wikipedia, Scientific Method. Available at: https://en.m.wikipedia.org/wiki/scientific-method.

the realization that scientific research cannot be embarked on by merely "studying or observing the fact"; no scientific research can be initiated unless some anomalies are identified in real life-world. Sir Isaac Newton, we are told, was propelled to formulate the law of Universal Gravitation (UG) by the falling of an apple from its tree. Of course, apples have been falling down before Newton was born and people have been seeing it fall without attaching any significance to the happening. The capacity to sense problems in the physical world, particularly problems whose solution have rippling effects on the solution of other anomalies, is a mark of scientific ingenuity. It is thus, an undeniable fact that scientific research oftentimes begins with some anomaly, and "aim at an order that links what may superficially seem to be unrelated facts".[3]

As soon as the researcher has found a problem, he could make a tentative solution of the problem he has singled out. Here, cognizance and familiarity with the subject matter becomes very significant. For the fact, no scientist can even state the problem except he is well acquainted with the subject at hand. To clarify this point, an example can be gleaned from the history of science. In November 8, 1895, the German physicist Wilhelm Conrad Röentgen intercepted a burgeoning experiment on cathode-ray phenomena based on the glimmer of a barium platinocyanide screen somewhere in his laboratory. He did so because he not only saw that the blaze was an anomaly but also because he perceived it as a significant problem needing further examination. Having a working knowledge of the character of cathode rays, Röentgen formulated the hypothesis that the illumination was as a result of a new form of radiation dissimilar to cathode rays. Notably, only few scientific breakthroughs have exerted an immediate impact as Röentgen's discovery of X-rays as this caused an instantaneous revolution in the fields of physics and medicine.

Suffice it to say that not all conjectures as conceived by the researcher are pertinent to a particular problem. Still on the example given earlier, Roentgen did not identify the cause of

[3] Morris Cohen, et.al., An Introduction to Logic and Scientific Method, London: Routledge & Kegan Paul, 1963),199.

the radiation he noticed with the form or size of the instrument he was using at the time of his research, owing to the fact that there is no such causal relation between the form or size of the scientific equipment he used during the experiment which involves cathode rays and the glitter of barium platinocyanide screen. While some philosophers like Francis Bacon and John Stuart Mill hold the view that there are rules guiding scientific discoveries, facts have revealed that these rules cannot *sensu stricto*, be mechanically adopted to arrive at causal connections between events in the phenomena world. If there were standing rules which can lead to scientific discoveries, then the task of the scientist would have made easier. Invariably, issues about causal relation are usually issues about relevant hypothesis. As noted earlier, the scientist must be versed with the sort of causal nexus which the issue under investigation is capable of revealing in order to arrive at relevant hypothesis. It will be a mere waste of time if he thinks that he can arrive at a scientific discovery by the strict application of a set of rules.

Having got the relevant hypothesis, the scientist could then begin to gather additional facts which could be harbingers of the final solution. And it should not be surprising to find such a hypothesis different from the solution to the problem[4]. Fundamentally, scientific research begins with some facts which is considered by a scientist as problematic. However, these collections of facts are usually not enough to ensure that the researcher postulate a comprehensive explanation for them. Yet, they provide some preliminary hypothesis that would foster the search for additional facts. Roentgen gathered more facts to his preliminary hypothesis, having discovered that the effect he observed during the experiment on cathode rays was somewhat, a new form of radiation very similar to light.

It should be noted that a preliminary hypothesis and the collection of additional facts play interdependent roles and as such, they are inseparable. Rigorous scientific research demands a preliminary hypothesis to delineate the facts, but the added facts may evoke new hypotheses,

[4] Iving Copi, et.al, Introduction to Logic, (New York: Macmillan, 1994),543.

which may culminate to new facts, and these new facts could in turn suggest other hypotheses, etc.

As his research progresses, the scientist would come to a stage where he realises that the major facts needed for problem solving are available. Roentgen – who announced his discovery after seven active days – felt that he had a hypothesis that explained the data at his disposal. In order to formulate a more viable hypothesis that explains the initial problem and additional facts deduced from experiments, the scientists must thoroughly reflect. The culmination of such reflection, if prosperous, would be a scientific theory that provide an account for the available data. Invariably, all explanatory theories of science involve a creative process of both intuition, imagination and knowledge.

What is more, scientists are usually not satisfied with laws or theories that describe only those facts that were initially considered during the process of carrying out research; they usually fancy theories that go beyond the incipient data to the new ones whose awareness in lieu of subsisting scientific knowledge would have been unprecedented. This procedure entails a deductive development leading to further consequences. Scientists and epistemologists of science alike, place a lot of value on the explanatory prowess of scientific propositions, and this connotes that added facts should be derived from a sound theory with predictive value. From Roentgen's discovery that the reason behind the radiation was not the cathode rays but a new radiation comparable to light, he predicted some elements of the new radiation having discovered them already.

To ensure the scientific researcher is on the right track, the procedure of deducing testable consequences from a scientific must be well entrenched. This becomes very important for scientists because it helps them to bring to bear the hidden assumptions which can be empirically verified. For instance, Roentgen spent quality time investigating the constituents of the X-rays he predicted in the course of his examinations due to the point that scientific experiments are performed to test the effects of theories in addition to initial situations. Indeed, scientists emphasize more on theories that help them discover and infer a greater sort of true propositions. Seeing that no scientific theory can be authenticated as wholly true, as it is at best contingent upon subsequent research, we can infer that theories with more predictive value and better demonstrated causal nexus between heretofore unconnected phenomena are preferred to ones with less predictive potency of such causal links.

Our discussion so far connects more to the theoretical issues of scientific method in the quest to provide a well-seated understanding and explanation of the phenomena. But both theory and practice go hand in hand; theoretical issues about science are intricately connected to its practical problems, and vice-versa. Thus, when scientists postulate theories to capture phenomena these propositions usually have practical bearings. Tellingly, Roentgen's discovery and explanation of X-ray have been useful in addressing several practical problems; for instance, in medicine, X-rays have been used in the diagnosis and treatment of certain diseases. In most cases in science, anomalies engender theoretical development, and some theories are wittingly developed with the eagerness to provide answers to some questions and problems arising from the phenomenal world.

Nature of Scientific Experimentation and Objectivity

As mentioned earlier, scientific research is initiated by problems and these problems are not unconnected with some facts which the scientist considers as problematic. Although H.I. Brown[5] warns that observation of empirical fact is a complex venture, scientific research as an empirical discipline must fundamentally make connection with the phenomenal world through a careful method of observation. In our lived experiences in the world, the sense organs enable us to perceive matter within the background of our linguistically-mediated existence. Nonetheless, much as common observation and scientific observation are influenced via the senses, the latter goes beyond mere sensation and perception of things to the development of scientific equipment and instruments in order to detect that which mere sensation cannot readily

[5] Harold Brown, Observation and Objectivity, (New York: Oxford University Press, 1987),48-76.

perceive. This heuristic innovation has profound influence on the nature of scientific experimentation.

The process of scientific observation is conducted within the ambience of a theory (or sometimes theories) and this procedure is demonstrated in a number of ways: first, it suggests the kinds of items that exist; second, it reveals the appropriate equipment for observing them and, thirdly, it demonstrates how we are to construe the collected data from the instruments which helps observation. For instance, the discovery of the electron neutrino in 1959 by Clyde Cowan and Fred Reines[6] aptly illustrates the close connection between theory and scientific observation. It also underscores the complexity in upholding a strict distinction between observable and unobservable elements in scientific observation. With the advancement in scientific knowledge, better scientific equipment are devised to make the hitherto unobservable elements discernible. At a time in the history of science atoms, electrons, etc., were considered unobservables; now it is no longer the case as scientists conceive them as visible. But how can we justify this change in lieu of scientific practice? In his article: "Experimentation and Scientific Realism", Ian Hacking gave an interesting response to this question when he noted that:

> …it is not even that (scientists) use electrons to experiments on something else that makes it impossible to doubt electrons. Understanding some causal properties of electrons, you guess how to build a very ingenious complex devise that enables you to line up electrons the way you want, in order to see what will happen to something else.[7]

Ian Hacking's position is a pointer to a discussion of the role experiments plays in scientific research. As an enterprise with a major objective to explain the world, science must be firmly rooted in experiments because it is the experimental procedures of research that guarantee that

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[6] Frederick Reines, et.al., "Detection of the Free Neutrino", in *Physical Review,* Vol. 92.

[7] Ian Hacking, "Experimentation and Scientific Realism", in Tauber, A. (ed.). Science and the Quest for Reality, (London & Hampshire: Macmillan, 1997),164.

scientific theorizing sustain contact with the physical world. Scientific experimentation is a serious business as it takes, in some cases, a long period of data analysis to come up with useful information that scientist can utilise. Experimentation in science is a sifting process which furnishes “a reliable way of checking our empirical conjectures about the objective world”.[8] This process itself is grounded on measurements. Measurement is a well-structured process for scientific quantification of material nature targeted at enhancing the level of “reasonable agreement” between nature and theory.[9] When a discrepancy is noticed between the results of measurements and the numbers predicted with the aid of theories, it is required of the scientists to carefully identify the source of the problem. Generally, scientific research can be marked as a tasking and well-structured activity aimed at providing the necessary background for future scientific breakthroughs and entrenching the horizon of objectivity. Doubtless, measurement is an essential tool for such exercise.

Objectivity is a structural component of scientific methodology. So construed, it is “a value that informs how science is practiced and how scientific truths are discovered”.[10] In an attempt to unravel truth about the physical world, the scientist must aspire to eliminate prior commitments, emotional biases, etc.[11] Objectivity is frequently associated with the property of scientific measurement as the precision of a measurement can be verified independent of the scientific researcher. Thus, objectivity is closely knitted to the purpose of testability and reproducibility. For the results of measurement to be considered objective, it must be transmitted and made public. In effect, objectivity is preserved by the social and public character of science which imposes a mental discipline on the scientific researcher. However, epistemological concerns are raised as to the extent and nature of objectivity and truth in

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[8] Larry Laudan, “Explaining the Success of Science: Beyond Epistemic Realism and Relativism” in Cushing C.F, et.al, (eds.), *Science and Reality: Recent Work in the Philosophy of Science,* (Notre Dame: University of Notre Dame Press, 1984),83-105.
[9] Thomas Kuhn, *The Essential Tension,* (Chicago: Chicago University Press ltd, 1977),184.
[10] Wikipedia, Objectivity (Science) 2014. Available at: https://en.m.wikipedia.org/wiki/Objectivity_ (science).
[11] Lorraine Daston, *Objectivity* (USA: MIT Press ltd, 2010),3.

science. Since the process of object selection and measurement are ordinarily subjective and the results of that particular process are universalized to a broader system from which the object of study was selected, the conjectures are unavoidably prejudiced. Thus, while carrying out research, the scientist is expected to implement his research activity in agreement with the benchmarks of intersubjective process obtainable for himself and members of the scientific community.

Epistemological Models of Scientific Methodology

Arising from epistemological discussion of science are a number of ideologies of scientific method which can enhance our understanding of the operations of science. Owing to the remarkable achievement of science in interpreting the world, there is an expansive view that there must be something distinct about science which distinguishes it from other seemingly unscientific disciplines, such as psychoanalysis, astrology or even philosophy. Commend philosophers, they have, in many cases, addressed the criterion of demarcation between science and pseudo-science in a rational and essentialist manner in order to provide an adequate characterization of science.

The logical positivists, otherwise known as members of the Vienna circle, held that scientists attempt to justify the view that scientific knowledge is the only accurate kind of knowledge and that all traditional metaphysical books are to be set ablaze as its doctrines are meaningless. In effect, they proposed the verification criterion of meaning as the distinguishing factor for demarcating strict science from nonscience. They emphasized the process of induction through the accumulation of confirmed and verified empirical fact. The implication is that through continuous accumulation of this sort of evidence science progresses towards truth and objectivity which can be evaluated by probability calculus. Karl Popper refutes this inductivist explanatory model of science which illustrates that the increasing probability of scientific theories based on the accumulation of confirmed cases of a theory applicable to the available evidence as a mark of the predictive success of science. Thus, Popper prefers the hypothetico-deductive method to induction. For him, science proceeds by conjectures and refutation; and falsifiability rather than verifiability is the demarcating criterion between science and pseudo-science. Although the goal of science is to seek truth and objectivity, Popper thinks the scientist cannot be certain that he has arrived at truth until it is falsifiable and properly tested. A theory is said to be scientific if it can yield a prediction that contradicts experimental observations, that is, if it is testable or refutable in principle. A better way to enhance the growth of scientific knowledge is for scientists to formulate bold hypothesis that must be subjected to testing after which it is corroborated having passed the severe test. Popper's prerequisite for science "is for it to be singled out, once and for all in a positive sense but that its logical form shall be such that it can be singled out by means of empirical test".[12] Hence, the rationality of science is to be found in its refutability (falsifiability) and testability.

Popper's hypothetico-deductive model of science has some merits. Firstly, it furnishes a moderate view of scientific progress in terms of increasing verisimilitude (tentative truth) rather than by attaining certainty in scientific knowledge. Secondly, it places science on a sound rational ground than does the inductive methodology of science. Thirdly, falsification is a more organized way of addressing the problem of demarcation between science and nonscience.

However, Popper's view on the method of scientific inquiry has been criticised as his propositions run contrary to the existing procedure of scientific research. One, Popper was not consistent in his refutation of induction. As a matter of fact, falsification and corroboration possess elements of induction. This is precisely so because in an attempt to falsify or corroborate a hypothesis, we must proceed using the inductive method. As Feigl poignantly notes, "it is only by induction that we can assume that a well-refuted theory will be refuted".[13] Second, while we commend Popper for his criticism of the logical positivist on the ground of

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[12] Friday Ndubuisi, Epistemological Evaluation of Science (Lagos: Foresight Press, 2003),19.

[13] Herbert Feigl, "What Hume might have said to Kant (and a few questions about induction and meaning)' in the *Critical Approach to Science and Philosophy in Honour of Karl Popper,* Mario Bunge (ed.). (London: The Free Press of Glencoe, 1964), 49.

the criterion of demarcation which they identified with the verification principle, it should be stated that Popper's prescription was neither plausible because purely metaphysical propositions do not need to be falsified or corroborated by empirical testing as is the case of scientific conjectures. Generally, falsification as a principle of scientific inquiry raises more problems than it could solve. In real scientific practice, evidences are gathered by a scientist to strengthen his hypothesis not refute it.[14]

The inadequacies of the hypothetico-deductive model based on the principle of falsification have culminated in a historical angle to the philosophy of science. A major proponent of the historical theory of science is Thomas Kuhn. He points that a number of antagonistic explanatory models of the phenomenal world must exist before science as an empirical discipline can emerge. This period of theoretical mutiny ends as soon as one of the contending theories either provide answers to a difficult question which its rivals could not figure out. Normal science commences when the overarching explanation becomes accessible and accepted through some kind of consensus. So construed, normal science is research strongly rooted in past scientific successes, one which the scientific community recognized as the tentative foundation for future scientific practice. The primary aim of normal science is the disciplinary paradigm whose basic features are: "(a) symbolic generalizations, such as f=ma, $E=mc^2$ etc. (b) models, such as the depiction of an atom as a miniature solar system and (c) exemplars, which are concrete problem solutions accepted by scientists in a particular domain as providing the template for solving other related problems".[15]

Normal science progresses continuous refinements of the problems as well as the solutions which is actualized within the ambient of a disciplinary matrix which functions as the architecture for solving puzzles. However, a problem can degenerate into an anomaly which is further worsened into crisis; extraordinary science emerges when a theory successfully solves

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[14] Ndubuisi, Epistemological Evaluation of Science,154.

[15] Douglas Anele, "Scientific Method: An Introductory Expository" in *Philosophy, Logic & Philosophy of Science* Nduibuisi .F. (ed.) (Lagos: Foresight Press ltd 2011),196.

this crisis. At the same time, scientists do not rescind a theory except a better one is formulated. In determining between conflicting theories, logical and empirical considerations are relevant, though not determinative and they are enhanced by the consensus and sociology of commitment.

Kuhn adumbrates a revolutionary insight into the methodology of scientific inquiry which can be arrived at by addressing the methodological issues of science historically. He construes consensus as the touchstone scientific research which is practiced by scientists during normal science. Critics, however, have argued that it is difficult to see this level of consensus during normal science as Kuhn would have us believe. Kuhn has also been accused of wrongly underrating the utility of empirical and logical factors in deciding between competing alternative theories in science. Though the application of logical and empirical standard in choosing between theories are problematic, many scientists have been able to manage such difficulties, without abandoning completely these criteria.

Owing to the various disagreements amongst philosophers of science on what constitutes the core of scientific methodology, some scholars have proposed an epistemological anarchist view of scientific research. For instance, Paul Feyerabend has proposed this unconventional kind of view. He was very critical of Popper and Kuhn. In his view, if Popper's methodological proposition is applied resolutely, it will shut out science without substituting it with an alternative. Feyerabend also sees Kuhn's ideas as too obscure to engender any substantial methodology of science. In his work: *Against Method*[16], Feyerabend, himself an "irrationalist", proposes what we now call the state of anarchy and disunity in science. Science, for not a unified system but a collage in no need for methodology as it is, more or less, an impediment to the growth of science. Put differently, science is not one thing, but a collection of various research traditions, theories and practices. Instead of the principle of consensus and tenacity which Kuhn proposed, Feyerabend advocates the principle of anarchism which ensures

[16] See Paul Feyerabend, Against Method, (London: Verso Press ltd, 1975).

scientific progress. He reminds us of how various non-western cultures of the world had made remarkable advancement in the areas of technology, medicine, etc., without recourse to the methodology of science.

Feyerabend has excelled in bringing our attention to the issues we are likely to encounter if the methodological procedures of science are taking *sensu stricto*. His unconventional orientation of science is a functional corrective to the devastating influence of 'competent' intelligentsias on people's lives, making them slaves of their own existence.

Feyerabend erroneously exaggerates by placing antiquated practices and superstitious beliefs on a similar pedestal with modern science. It is foolhardy to think that the successes of scientific knowledge over other es is largely due to ideological situations that support science. Contrary to this view, science has abundantly improved our knowledge of material nature over millennia, and through its usage of technology, it has modified the nature of our heuristic exercises to a level unequalled by prior methodological orientations. The principles of verification, predictability and coherence are intrinsically connected with the advancement of science in explaining the natural world. Moreover, Feyerabend's theory of "anything goes" is spurious. If taken to heart, nothing will be taken out of science. A sorcerer, for example, could claim to be a scientist; an astronomer need not go beyond the Bible to investigate the solar system and heavenly bodies. Thus, it can be easily gleaned from the above that progress in science is marked by the fact that some methodologies are more pragmatic in explaining the workings of nature, though they do not authenticate certainty, truth and objectivity.

In an attempt to address the nature of truth and objectivity in science, some neo-pragmatic methodological approaches to science have evolved. One such methodological orientation is the Natural Ontological Attitude (NOA) to science advanced by the philosopher of science, Arthur Fine. The NOA is a minimalist thesis with three distinct, but correlated parts: (a) its investigation of the realism-antirealism contention which influences the shift towards minimalism and hermeneutics. (b) its overwhelming anti-essentialist perspective on the ontology of science. (c) its antirepresentational orientation of truth and objectivity. NOA attempts to resolve the realism-antirealism debate by upholding the view that they both furnish insights towards understanding the practice of science, though their interpretations are unwarranted. Fine attributes to realism and antirealism, the constant insistence that science requires interpretation and totalizing narratives in order to be authenticated. Just as we rely on our senses as a means of substantiating the constituents of quotidian experiences, so too do we accept science and its system of inquiry.[17] NOA demands that we view science in the usual referential way in which "when an object stands in a referred-to relation, we can accept the existence claims along with the resulting commitments to related properties and claims[18]. Thus, NOA suggests that science should be allowed to "speak for itself" which makes science intelligible as it satisfies our intuition that scientific practice is purely an objective activity without being realist or antirealist in perspective. Many have criticised Fine's NOA. One of such critics is Alan Musgrave[19] who accused NOA as essentially sold to realism and its deployment of "usual referential semantics" imply a particular theory of truth. For him, Fine distorts the manifold stance of antirealists in respect to their position of truth (or what Musgrave term the "core"). Fine's NOA seems to be mistaken when he suggests that explanatory success of science is unconnected to its truth. In connection to this, Robert Klee[20] and Richard Schlagel argued that the NOA is an inconsistent and implausible methodological orientation of science. Despite the criticisms, Arthur Fine's NOA remains a useful interpretation for scientific practice as it provides a reconciliatory ground for the realist/antirealist debate on the nature of truth and objectivity in science. In addition, Fine points that although scientists may discover more facts and evidences about the empirical world, we must not approximate these advances in scientific

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[17] Arthur Fine, "The Natural Ontological Attitude" in *The Shaky Game,* (Chicago: The University of Chicago Press,1986), 116.
[18] Ibid, 130
[19] See Alan Musgrave, "NOA'S Ark – Fine for Realism". *The Philosophical Quarterly* 39,157 (1989): 383-398.
[20] Robert Klee, *Introduction to the Philosophy of Science: Cutting Nature at its Seams,* (Oxford: Oxford University Press, 1997), 238.

knowledge of an entity with what the entity itself is. Science, is but one of the many attempts to capture the world and its explanatory successes should not be confused with truth.

Conclusion

Our discourse thus far can be tied together by emphasizing the usefulness of philosophical articulation of scientific research for both scientists and nonscientists. It unravels the infelicities and hidden assumptions of scientific inquiry in lieu of the prerequisite for the potentiality of empirical knowledge. As such, the growth of scientific knowledge is ensured by a continuous epistemological assessment of its basic assumptions and methodological activities**.**

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