THE SCIENTIFIC MIND - EVER SEARCHING, NEVER CERTAIN

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Abstract

This article examines the nature of scientific thought and looks at how "the scientific method" has propelled mankind's understanding of natural phenomena from the embryonic metaphysics to the present-day quantum and plasma physics. The scientific mind is always in search of ways to improve the present knowledge about nature, and is never satisfied that the present knowledge is "the truth, the whole truth, and nothing but the truth."

"Science is grounded on a firm foundation of doubt" - Don Cupitt

"The moderns have subjected the phenomena of nature to the laws of mathematics" - Isaac Newton.

The scholastic adage, "all men by nature desire to know" has driven philosophers, from as far back as the Aristotelean era, to ponder the question "What are the conditions of knowing?" Or, simply put, "how do you know that you know something?" Under what conditions can something be called knowledge?

Introduction

Addressing the International Conference on Science for Development (1984)[1], Professor Abdus Salam propounded and strongly defended a view that "it should be noticed that the boy is not said to know how to play chess, if all he can do is recite the rules accurately. He must be able to make the required moves. But he is said to know how to play if, although he cannot recite the rules, he normally does make the required moves, avoid the forbidden moves and protest if his opponent makes forbidden moves. His knowledge how is excercised primarily in the moves that he makes or concedes, and in the moves he avoids or vetoes. So long as he can observe the rules, we do not care if he cannot also formulate them. It is what he does on the board that shows whether or not he knows the rules in the executive way of being able to apply them." In essence, we must distinguish between "knowing how" and "knowing that."

Lord Kelvin had the famous, and highly controversial, view that "when you can measure what you are speaking about and express it in numbers, you know something about it". Less controversial was the philosophy of Plato (c 427-347 BC), that a person (X) knows something (P) if (1) P is **true** (2) X **believes** that P is true and (3) X is justified in believing that P is true.

Many modern-day educational philosophers including D.W. Hamlyn and Alfred Jules Ayer more or less share Plato's views. In his book Education and the Nature of Knowledge, Robert Brownhill lists five features a piece of knowledge must have if it is to be accepted as objective knowledge[2]:-

(1) The knowledge must refer to a reality which is separate from ourselves, i.e. that a distinction has to be drawn between what the world is, and what we happen to say about it.

(2) As there is an independent reality, we can test our beliefs by reference to this reality, and without this possibility of testability, there can be no objectivity - i.e. knowledge must be testable.

(3) Theoretical knowledge must not be tied to our senses but must stand on its own feet.

(4) Ideally, the knowledge should be in a mathematical form which can be understood by and demand acceptance from other rational beings.

(5) The knowledge or theory has to have public communicability so that we can understand it whatever our location and situation.

On digesting these thought-provoking philosophical viewpoints, it becomes obvious that the very foundation of knowledge is truth. Something cannot be called knowledge if it lacks truth. So, the logical question arises, "What is truth?" That's the very same question which Pontious Pilate once directed at Our Lord Jesus Christ - and which Jesus wisely refused to answer, accomplished philosopher though he was. Nor did Pilate even expect an answer!

Philosophers over the centuries have wrestled with this very question about truth. How do we recognise truth? How do we know that something is true? We cannot even rely on our five senses to ascertain truth because, as Plato has often been quoted, "... a doubt about the reality of the senses is easily raised, since there may even be a doubt whether we are awake, or in a dream, or merely hallucinating." We might pick up any old dictionary and extract several words given as meanings for truth-reality, authenticity, exactness, honesty, fact, rightness, veracity, verisimilitude, verity, - none of which is easy to measure or confirm or prove or defend. "A thing is not necessarily true just because a man dies for it" - argues Oscar Wilde (1854-1900). "The fact that we are committed to something cannot be taken as an indication that it is the truth. The truth is independent of our beliefs" writes Robert Brownhill in his book Education and the Nature of Knowledge.[3] It is part of Polanyi's argument that "the scientist's search for truth is a search for a truth about external reality, and that the system of ideas that make up science contains the scientist's belief about the true contents of reality".[4]

In this article, we shall examine how scientists, over the centuries, have grappled with this problem of probing and analysing the deep secrets of nature, all in a quest to arrive at the **truth** about natural phenomena.

If we consider science as the systematic investigation of reality by **experimentation, observation,** and **inference**, then among early civilizations, science did not exist. Although discoveries were made, they were piecemeal, not systematic. Myth and religion completely dominated as the modes for explaining natural phenomena. This "status quo" began to change with the inspired speculations by early Greek philosophers. We shall see in this discussion how the foundations laid down by these Greek philosophers were revised, cast aside, or modified, strengthened, and then built upon by subsequent scientists. We shall see that no scientific conclusion, at any stage, was regarded as final. No scientific conclusion was regarded as "the truth, the whole truth, and nothing but the truth." Instead, each conclusion was subsequently scrutinized, revised, modified and built upon, or else was completely discarded. This procedure has since become the "modus operandi" of the scientific fraternity.

The Scientific Method

The spectacular success of the natural sciences from the 17th century onwards prompted a search for "the scientific method". Until the 20th century, this was seen as the search for a general set of instructions or recipe for getting scientific results. Typically this would involve experimentation, observation, and inference. But nowadays, it has become an attempt to describe the general aims of science. The scientific method has broadened and is now thought of as whatever in practice serves to promote the aims of science. But whichever way we choose to look at it, the one essential (indeed indispensable) ingredient is the ability to draw **correct inference** from observed facts. In any scientific investigation of reality, the ability to draw correct inference is a "sine qua non".

Types of Inference

An inference may be **deductive** or **inductive.** In each case, we begin with a given fact or set of facts called premise(s), and draw a conclusion (inference) based on the premise(s).

Deductive Inference

Consider the following premises: All dogs are mammals. All mammals have kidneys. We now **deduce** the conclusion: All dogs have kidneys. This deductive inference which we have made is true under any conditions. The defining characteristic of valid deductive argument is that it is impossible for all the premises to be true and the conclusion false. This is because the information contained in the conclusion is already stored in the premises, taken collectively. All mathematical calculations, all steps in a mathematical computation are deductive inferences.

Suppose the given premises are: Many Americans are tall and huge. All Americans who teach in this college are white. And suppose we draw the inference: All Americans are tall, huge white teachers. This conclusion is obviously false. The defining characteristic of an inductive argument is that the information contained in the argument **goes beyond** the information contained in the premise(s). Hence, it is possible for inductive arguments to let us down, i.e. for the premise(s) to be true but the conclusion false. Consider another example. Suppose the premises are: Men's skulls are generally bigger than women's skulls. Bigger skulls contain bigger brains. And suppose that our inductive inference is: Men are generally more intelligent than women. This conclusion is at best controversial, and most likely it is false, even though the premises are true.

Deductive inferences, no matter how long, have been codified and the rules for their validity worked out. Inductive inferences have resisted codification and their validity is controversial. Explanations of particular scientific experimental results by theories are deductive inferences since all the information contained in the theory are already stored in the observed experimental results. Justification of a theory by experimental results uses inductive inferences although of a kind more complex than the simple examples given above. Such a justification, therefore, may or may not be true. For this reason, we cannot set up an experiment to prove a theory. Rather we set up a theory to explain observed experimental results.

Origin of "Marriage" between Science and Mathematics

All mathematical calculations, all steps in a mathematical computation are deductive inferences. It is not surprising therefore, that in their tough quest to arrive at, prove or defend the truth about natural phenomena, scientists (and in particular physicists), were forced to turn to and embrace mathematics - the systematic and logical study of relationships between qualities and magnitudes expressed in numbers and symbols. Newton had to concede that "...the moderns have subjected the phenomena of nature to the laws of mathematics", a statement which Bertrand Arthur Russell (1872-1970)[5] wholly agrees with when he asserts "The way to get at the nature of any subject matter you are looking at is by analysis ... by **logic**, until you get to the atom of the matter". Russell was the natural philosopher and mathematician whose work went a long way towards giving natural philosophy a scientific base. The need for a strong bond between physics and mathematics is reaffirmed by Peter Stein in his book Measurement Engineering[6] where he argues that "...measurement consists of information transfer, with accompanying energy transfer. Energy cannot be drawn from a system without altering its behaviour - hence all measurements affect the quantity to be measured. Measurement is therefore a carefully balanced combination of applied physics (energy conversion) and applied mathematics (information transfer)".

The importance of measurement in any area of science cannot be overemphasized, and measurement itself is a blend of applied physics and applied mathematics.

Even long before Newton, physicists recognized the need for a powerful vehicle through which scientific thought could be transferred. The powerful vehicle was mathematics. Mathematics made scientific reasoning very coherent, very **logical**, very concise, and very elegant. Armed with sound mathematical skills, a physical scientist does not need to be Cicero to articulate, defend, or disseminate his ideas. Indeed, it was not until mathematical approach gained a firm hold in the study of physics that the really great strides in the development of the subject became possible.

State of the "Marriage"

It is not surprising that most of the early physicists were also very accomplished mathematicians. When a new idea in physics was under investigation, it often became necessary to develop a new mathematical method, if there was no existing mathematical method that could deal with the new idea. Thus Archimedes (c 287-212 BC), mathematician, physicist and inventor, had to fix the value of pi, had to devise methods for calculating areas bound by curves. These mathematical operations were all necessary tools he used in investigating his ideas in hydrostatics which eventually led to his formulation of the Archimedes Principle. For his part, Isaac Newton, mathematician and physicist, in his quest to set out a system of the universe based on physical laws, to formulate laws of gravitation and motion, had to do a great pioneering work in differential and integral calculus. His discovery of the binomial theorem in algebra was also linked to his work in physics. Calculus, a mathematical process of reasoning by use of symbols, was in fact originally studied by Archimedes and further advanced by Rene Descartes (1596-1650). Descartes, a French mathematician and philosopher, was not himself a physicist but his work in mathematics facilitated the work of contemporary physicists. Descartes founded Cartesianism, based on distinction between spirit and matter, summed up in his famous dictum "cognito, ergo sum" - "I think, therefore, I am". We shall have cause to return to Cartesianism later in this article, but Descartes is regarded as the founder of analytical geometry, crucial to tackling many physical problems.

Differential calculus, a mathematical process concerned with problems of change of function, which was devised by Isaac Newton and Gottfried Wilhelm Leibrits (1646-1716), was further advanced by Leibritz, who also introduced new forms of integral calculus. Thereafter, integral calculus - a branch of higher mathematics which constructs relationships of variables from rates of change e.g. a method of finding areas enclosed by curves - became a very powerful tool, a very potent weapon, in the hands of contemporary and subsequent physicists.

In the 18th century, the Swiss mathematician Leonard Euler (1707-1783), considered one of the founders of modern mathematics, developed new methods of analysis, building on the strong and enduring foundations laid down by the giants before him. And by the 19th century, mathematics had reached a very advanced state, and the bond between physics and mathematics had grown so strong that there evolved certain physicists who devoted their time to simply using mathematics to postulate new principles and ideas in physics. These became known as theoretical physicists (or mathematical physicists). They rarely entered an experimental physics laboratory. Yet they were able to predict many physical laws and principles using mathematics alone.

James Clerk Maxwell (1832-1879), a Scottish physicist, developed his immortal electromagnet field theory on a purely mathematical basis, yielding the famous

Maxwell's equations. Equally astonishing was the work of Erwin Schrodinger (1887-1961), an Austrian theoretical physicist. Working on the atomic theory, Schrodinger arrived at a mathematical formulation of wave mechanics which ranks as one of the showpieces of 20th century physics. For his efforts, he shared the Nobel Prize for Physics in 1933 with P.A.M. Dirac. Albert Einstein's theory of relativity, perfected in the middle of the 20th century, was essentially the offspring of this "marriage" between mathematics and physics. Indeed, even before the 20th century, mathematics had become the universal language of physics.

Physics, A Paradigm of Science

No branch of science is as well suited to mathematical thinking as physics is. It is because of this strong "marriage" between mathematics and physics that most arguments in physics are deductive in nature and are, therefore, less likely to let the scientist down, compared to arguments in other branches of science. This is, therefore, the reason why physics is regarded as a paradigm of science, a model of what scientific thought should be like.

It is also the reason why we have been using, and will continue to use the words **science** and **physics** interchangeably throughout this article. When precise mathematical concepts are used in formulating scientific theory (as in physics), then the application of such a theory to a physical reality will simply become a calculation in applied mathematics. This is the feature that makes physical theories so comprehensive, and such precise predictors. For examples, Isaac Newton used only four laws (three in mechanics plus one on universal gravitation) to explain not only the orbits of the moon and planets, but also such simpler phenomena as the rate at which a body falls, the motion of the pendulum, and even a simplified version of the relation between the temperature, pressure and volume of a gas. Thus, a small set of physical principles can be used to explain such diverse macroscopic and microscopic natural phenomena. The use of mathematical arguments also allows physicists to tackle a particular problem from different angles. If the same results are arrived at via different routes, the conclusion becomes even more plausible and more acceptable. A beautiful example is the brilliant way in which Newton arrived at, and confirmed Kepler's third law of Planetary Motion starting from a completely different conception. Physicists indeed love the dictum "e pluribus unum"-"out of many (approaches) one (conclusion)." Mathematical calculations (such as those in physics) are logical, deductive inferences. Hence, the central role of mathematics in physics. Theories employing non-mathematical concepts could not achieve such comprehensiveness and precision.

However, not all successful sciences match the paradigm of physics. For instance, Darwin's theory of evolution and Pasteur's germ theory of disease are examples of theories using non-mathematical concepts. But nowadays even biologists are seeking to use quantitative mathematical concepts wherever possible. Never-the-less, we are not trying here to imply that the search for knowledge and certainty must always be a mathematical exercise. As pointed out by Robert Brownhill in his book Education and the Nature of Knowledge, "...Mathematics was to be taken as the model for the acquisition of knowledge, but in practice, as Descartes (one of the very architects of the idea), himself was to find out, this was to prove very difficult, as the real world cannot always be explained with mathematical precision".[7]

Milestones in the History of Science

We can chart our future clearly and wisely only when we know the path that has led us to the present. Having had a brief look at the workings of the scientific method, the "modus operandi" of the scientific mind, and having seen the monumental task facing the scientist in his quest for knowledge, certainty and truth, we realize why the scientist was forced to embrace mathematics.

Were we to examine a chronological history of science[8], we would begin with the metallurgic experiment of the ancient Summerians (3500-3000 BC) and proceed milestone by milestone to Earnest Rutherford's discovery of the atomic nucleus, the theories of special and general relativity formulated by Albert Einstein (1879-1955) and the quantum theory of Max Plank (1858-1947).

Our journey would lead us to observe all along how the scientific method (of forever searching, never certain), was able to propel science from one peak to another. It was Danish physicist Niels Bohr's (1885-1962) application of the quantum theory to Rutherford's atom which resulted in a major revision of classical physics.

Understanding the structure of the atom and the tremendous forces locked into it led to the development of nuclear power and nuclear weapons. Today's science is dominated by expensive technology and extreme specialization. In physics, subatomic particles continue to be investigated and are thought to hold the key to understanding the origin and the ultimate nature of the universe. In biology, genetic engineering has become feasible and may produce untold benefits - or otherwise.

The Ultimate Goal of Science

Full comprehensiveness is an ideal for which science is striving and which is yet to be achieved. The two current leading theories, quantum mechanics (which explains atomic processes), and general theory of relativity (which explains astronomical processes), are mutually inconsistent, although both are firmly accepted by all physicists. But comprehensiveness remains an ideal of physics because physicists recognize this inconsistency as a problem requiring solution.

Surprisingly, a theory can be accepted as true even though it is known to make some false predictions. For instance, it was well-known in the 19th century that Newton's laws were so successful elsewhere, 19th century physicists regarded Mercury's orbit as an unexplained anomaly that did not shake their belief in Newton's laws. Only after these laws were **superceded** by the theory of relativity was the orbit of Mercury regarded as one of the facts that refuted Newton's laws.

Let us look a little more closely at two other major revisions/rejections of scientific theories.

The Changing Science of Motion

The ancient scholastic adage "Ignorato Motu, Ignoratur natura" - (who knows not motion, knows not nature), indicates that the ancient Greeks did realize the importance of the concept of motion in the world of physical sciences. Hence there was a great speculation in ancient Greece about the nature of motion. The Aristotelean concept of motion was based on the axiom that every motion presupposes a mover - "Omne quod movetur ab alio movetur" i.e. "all that moves is moved by something else" i.e. the mover must either be present in the moving body, or else it must be in direct contact with the moving body. Action-at-a-distance was completely rejected by Aristotle as inconceivable. A motor must always be a "motor conjunctus" i.e. must be connected with the moving body. It was easy to say that every motion presupposes a mover. What wasn't so easy to do was identify exactly what this was! For all moving celestial bodies, the mover was God (with a considerable amount of help from his angels!). Living things, (corpora animata) moved "a se" i.e. by themselves. What presented the greatest embarrasment to Aristotle was the motion of terrestial objects i.e. "corpora inanimata" or inanimate things, e.g. falling bodies. As far as inanimate objects were concerned, motion "a se" must be excluded. Also, since action-at-a-distance was unacceptable to Aristotle, it must also be ruled out. So Aristotle carefully avoided making an ambiguous statement about the issue.

This left subsequent scientists no choice but to discard the whole idea of "motor conjunctus" and the belief that "all that moves is moved by something else". Gradually the concept of action-at-a-distance and the concept of fields of force replaced Aristotle's theories.

Classical vs. Quantum and Relativistic Mechanics

Another classic example of how scientific theories are continuously being reviewed, modified or even superceded is the transition from classical (Newtonian) to quantum and relativistic mechanics. The physical world is not as simple as the theories of Newton's classical mechanics supposed, although such views are appropriate simplifications for large bodies moving relatively slowly with respect to the observer. **Quantum mechanics** is the only correct description of effects on an atomic scale, and **special relativity** must be used when speeds approaching the speed of light with respect to the observer are concerned. Simply put, Newton's classical mechanics is not correct for describing microscopic (subatomic) phenomena, nor can it be used for bodies moving at very high speeds with respect to the observer. The transition from Newtonian to quantum and relativistic mechanics is a beautiful illustration of the dictum "science claims no finality".

Always Room for Error

Descartes provides a typical example of a philosopher who was searching for certainty, and in doing so, produced an exceedingly individualistic approach to understanding reality. He believed that knowledge and certainty could be gained by the individual knower who was prepared to follow the Cartesian method of **constructive scepticism**[9] doubting all our previous beliefs until we arrive at some point where we could doubt no longer. This idea gave birth to his famous dictum "cognito, ergo sum" - "I think, therefore, I am".

But Descartes found out to his dismay that it was indeed very difficult to arrive at certainty. Indeed, scientists are always conscious of the fact that whatever scientific knowledge they possess is imperfect and is therefore liable to be erroneous. In this respect, scientists differ from dogmatic believers who think that their beliefs cannot possibly be wrong. It is important to believe in one's own ideas - consider St. Agustine's "credo ut intelligam" ("I believe so that I can understand") - but the fact that we are committed to something cannot be taken as an indication that it is the truth. The truth is independent of our beilefs![10] There are people who still believe that the Earth is the centre of the Universe or that the Earth is flat and circular. Typical of these strange groups of dogmatic believers is the Flat Earth Society of America. It boasts that it has 200 members who are science graduates. The president of the society, Charles K. Johnson, is vehement about "scientific dishonesty". Writing in the Flat Earth News[11], he says that conventional scientists are "liars" and "demented dope fiends". When shown a photograph of the Earth, taken from space, with a remark that it certainly looked like a sphere, he replied "Yes, it would, to an untrained eye." It is great fun arguing with people like these, but you can never hope to win because they will not admit any argument that contradicts their beliefs, no matter how strong the evidence supporting the argument.

There are also people who belong to the Bible Science Association[12] and believe that the Earth is the centre of the Universe, with the sun revolving around it. This group publishes the Bulletin of Tychonian Society. They think the Copernican theory (heliocentric system of the Universe) is a "Satanic conterfeit", a ploy to discredit the Bible. John Hampton of this society describes the Copernican theory as "that Satanic device of a round and revolving globe, which sets scripture, reason and facts at defiance".[13] Flat-Earthers can never be beaten in an argument because they know they can never be wrong. To the scientist, this fact that they can never be wrong is their greatest weakness. As Clerk Maxwell once put it, "Dogmatic believers are never in doubt, but often in error".

Conclusion

Both the Polanyian analysis of knowledge and the Oakeshottian analysis of models of experience, suggest an **uncertainty** at the heart of the educational task, and leads us to wonder whether the ideas and traditions we pass over to our children are merely transient products.[14] Indeed, Polanyi completely rejects the argument that a theory can be conclusively tested.[15] The fact that scientists are aware that there is always some element of doubt in their present knowledge makes science so dynamic, so progressive, so self-rejuvenating. For this reason, scientists are always in further search for further ways to improve their present knowledge of and explanations of, natural phenomena.

Scientists are never satisfied that the ultimate knowledge about nature has been attained. Present theories are in constant review, under constant constructive criticism, and undergoing continous improvements. As Karl Popper (1902-) succintly put it, "knowledge is better advanced by scientists trying to **disprove** theories, rather than attempting to **prove** them".

All scientists know that their picture of the Universe is fallible and likely to be changed as further discoveries are made. The essential of any theory is that it should be, in Sir Karl's phrase "falsifiable" i.e. open to disproof. Listen to this:

"Sir Karl Popper
Never told a whopper
He knows he's liable
to be falsifiable"[16]

Notice however, that Sir Karl's views are still related to the Cartesian desire for certainty. The truth is no longer manifest and science is tentative and will remain tentative forever.[17] But, at least we can get rid of false scientific hypotheses, and we can distinguish scientific statements from metaphysical ones by putting scientific statements in a **testable** form. We can at least know that we are mistaken! Yes indeed, science claims no finality, and as Don Cupitt put it, "Science is grounded on a firm foundation of doubt."

Footnotes

(1) Abdus Salem in his opening address to the "Conference on Science Transfer for Development", at the International Centre for Theoretical Physics, Trieste, Italy, October 8th, 1984. (The author attended the conference).

(2) Brownhill, Robert. Education and the Nature of Knowledge, edited by P. J. Hills. Beckenham, Kent: Croom Helm Ltd. 1983, pp 11-12.

(3) Ibid. p 123.

(4) Ibid. p 96.

(5) Russell, Arthur, Bertrand. Change and Challenge in American Education. Boston: Houghton Miffin and Co.m 1965, p 39.

(6) Stein, Peter K. Measurement Engineering Vol. I, "Basic Principles" 3rd Ed. Phoenix, Arizona: Stein Engineering Services, 1964, p 149.

(7) Brownhill, Robert. Education and the Nature of Knowledge, edited by P. J. Hills. Beckenham, Kent: Croom Helm Ltd., 1983, p 13.

(8) Barkow, Ben. The History of Science, A Contribution to The Guiness Encyclopedia. Middlesex: Guiness Publishing Ltd., 1990, pp 60-61.

(9) Brownhill, Robert. Education and the Nature of Knowledge, edited by P. J. Hills. Beckenham, Kent: Croom Helm Ltd., 1983, p 13.

(10) Ibid. p 123.

(11) Extract from Lockett, Keith. Physics in the Real World. Cambridge: Cambridge University Press, 1990, p 40.

(12) Ibid. p 41.

(13) Ibid. p 41.

(14) Brownhill, Robert. Education and the Nature of Knowledge, edited by P. J. Hills. Beckenham, Kent: Croom, Helm Ltd., 1983, p 121.

(15) Ibid. p 121.

(16) Lockett, Keith. Physics in the Real World. Cambridge: Cambridge University Press, 1990, p 41.

(17) Brownhill, Robert. Education and the Nature of Knowledge, edited by P. J. Hills. Beckenham, Kent: Croom Helm Ltd., 1983, p 18.

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