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Communication

"Shackles of Science": A Reappraisal of Scientific Innovations, Academic Advances, and Their Appreciation

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ABSTRACT

Science evolves over a gentle arc spanning centuries, with scientists building upon and extending the hypotheses and discoveries of their forebears when nurturing their own work from ideation to crystallization and finally implementation. However, evidence suggests several limitations of our modern academic pursuits including major inertia and epistemological biases to implement even major advancements.

For instance, the transformative uncertainty principles of quantum mechanics are yet to be satisfactorily integrated in modern analyses and publications, even almost a century after Heisenberg received the Nobel prize for these. Another example is ever expanding reliance on mathematics to validate the hypotheses of Physics, and undermine the opinions to the contrary. In addition, modern science limits itself to the era post fifteenth century and hastily rejects premodern achievements despite glaring examples.

This reluctance and inertia to capitalize on existing knowledge is a challenge that imperils our intellectual pursuits. A salient facet of science is "the willingness to admit ignorance". Only on this foundational principle can science meaningfully evolve. It is time we take a step back to evaluate widely accepted and foundational premises of modern science and institute structured processes to implement the treasure trove of knowledge amassed by our predecessors. This essay highlights some of the opportunities that can and should be availed capitalizing upon the recent developments of computational and analytical capabilities along with artificial intelligence.

Keywords: uncertainty principle; limits of mathematics; validation models; holistic approach

Introduction

"If I have seen further, it is by standing on the shoulders of giants." –Sir Isaac Newton

Every scientist, from benchtop to bedside, is aware of these famous words Sir Isaac Newton (1642-1727) wrote in a letter to a colleague in 1675. In other words, we can see more than our forebears not by virtue of our superior intellect but rather because of the solid foundation laid for us. In its zeal for "new discoveries," however, modern science might be overlooking this foundational dictum. Although science undoubtedly has made significant strides, it continues to be confronted by not only a significant lag in integrating acquired knowledge but a surprising undercurrent of reluctance to do so. Why should this be so? The chief aim of this essay is to address this question by considering some limitations of modern science, including its span, "language," validation models, and other deeply ingrained biases.

Evolution of knowledge is initiated and underpinned by the intellectual curiosity which may or may not immediately translate into useful discoveries. However, only by supporting such fundamental exploration without hampering its flow with the scrutiny of pragmatism can we expect theories to crystallize. A recent and celebrated example is the supposed "lightning speed" with which Covid-19 vaccines were developed and brought to market. In truth, the conceptual framework for the use of vaccines was articulated nearly two centuries ago by the French physiologist Dr. Claude Bernard in his theory of the "Milieu Intérieur" (*1-3*). The concept somehow survived the vehement challenges posed by Robert Koch's Germ Theory of diseases (*4*) and was validated only in 1796, when the first successful vaccine was developed for smallpox (*5*). Ever since, this paradigm has received major impetus with vaccines leading to near eradication of diseases such as tetanus, rubella, measles, polio, and chickenpox, among others. Within the last decade, application of Bernard's paradigm has revolutionized even the cancer treatment landscape, with immuno-oncology demonstrating unimaginable clinical outcomes in patients. The concept was recently recognized by a Nobel Prize in Physiology and Medicine to Drs. James P. Allison and Tasuku Honjo in 2018 (*6-8*).

Evolution over centuries also marks the field of physics, which advanced through stages of classical physics, quantum mechanics, and string theory. However, the concept of Quantum Entanglement that Albert Einstein proposed in 1935, only now has started producing unbreakable computer security, new kinds of communication systems, superfast computers, and other advancements. In October, 2022, Alain Aspect, John Clauser and Anton Zeilinger received Nobel prize further work on Quantum Entanglement.

Another example is the concept of 'gravitational waves' predicted by Einstein in 1916 but proved 100 years later only, culminating in the 2017 Nobel Prize. (*9-11*). These waves are now revolutionizing our understanding of the universe, including black holes, extreme gravity, neutron stars, cosmology, gamma-ray bursts, and stellar evolution. The most exciting discoveries, however, will be the one no one expects yet (*12*).

These are only some of the real-world examples of Newton's quote on intellectual leviathans and behooves us to meticulously evaluate, acknowledge, and integrate the work done by our predecessors. However, there seems to be a significant inertia as well as reluctance to capitalize upon the work done previously that decelerate the progress that could have been achieved. Let us look at some examples of above-mentioned inertia in the contemporary scientific methodologies, and how they limit scholarship.

In the realm of physics, the gold standard is to employ mathematical formulae to prove hypotheses of physics. Relationships between mathematics and the physical world have been contemplated since the era of the Pythagoras (570-490 BCE) but were cemented in modern science by astronomer, physicist, and engineer

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Galileo (1564-1642), who proposed that whatever cannot be measured and quantified is not scientific. His emphasis on quantification so profoundly shaped the evolution and contours of science that mathematics became the fundamental "lingua franca" of modern science and its practitioners (*13*,*14*).

Not without debate, however. While mathematics undoubtedly works on simplified models of reality, overemphasis on it is a viral reductionism that disintegrates holistic concepts into imaginary dualisms (15-19). Nevertheless, a significant number of scientists and mathematicians subscribe to a Platonist view that mathematics is indeed the "mother tongue" of science and not a product of human imagination (*20*). On the other hand, some including Albert Einstein (1879-1955) endorse the miraculous strengths of mathematics but also construe it as a product of human imagination (*21*). Regardless of its origin, we may all agree that mathematics (even with its elaborate syntax and vocabulary) remains merely a language, and that, by definition, languages are limiting (*22*). Like any other language, mathematics also has innate constraints in capturing the full spectrum of reality. Modern science seems oblivious to the fact that overemphasis on data and our zeal to connect them through mathematical models weaves a sieved *weltanschauung* (worldview) through which may transude vast dynamic, qualitative, and experiential aspects of reality.

Interestingly, as classical physics transitioned into quantum mechanics, German theoretical physicist Werner Heisenberg (1901–1976) indirectly addressed the above experiential lacunae when he utilized mathematics to highlight the fundamental limitation of this approach in his "Uncertainty Principle"; a set of mathematical relations that measure the extent to which the scientist influences properties of observed objects through the process of measurement (23,24). The fact that scientists hence cannot play the role of detached and objective observers, leads one to wonder whether the inferences of physicists with their mathematical validations are also not mere approximations? The challenge was aptly summarized by Einstein in his 1921

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lecture "Geometry and Experience": "As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality" (*25*).

In addition to the aforementioned limitations of validation models, even their application in modern scientific literature significantly lags scientific evolution. Clearly an indispensable component of validation is the mathematical quantification of models with reliable data and aligning the plausibility of the output to with past findings. However, experts concur that this methodology per se is insufficient unless the participatory approaches, that take into account the impact of the oberver's bias, are themselves integrated into validation (26). Yet this view has yet to be implemented adequately even 100 years after Heisenberg's uncertainty principle and even in the midst of modern string theory which irrefutably highlights the interdependencies of observations and the known as well as unknown confounding factors (*26*). Despite these limitations, while many scientists blithely embrace the "approximations" of modern science as proven facts, if their hypothesis fits in to a mathematical model.

In life sciences, a scientific hypothesis is considered "proven" if the so-called

"p" value is less than 0.05, or the probability of its reproducibility exceeds 95%. In normal conversation, this would be tantamount to claiming that what I state is more than 95% true. Granted that this sort of statistical formulation underlies the evolution of science and has enabled life sciences to effect enormous reductions in morbidity and mortality and enhance patient well-being; yet we must still remember that, while probability-driven scientific conclusions are robust, they are still mere approximation of reality. What about the remaining 5%? Termed "outliers," such infrequent events can still be devastating; a tangential example occurred in the 2008 global financial meltdown, which has been chronicled in the bestselling volume, *The Black Swan* (27).

Another major limitation of modern science is the so-called “Cartesian Divide”: an attempt to understand the whole by studying the parts. The concept originated in antiquity, with philosophers Socrates and Aristotle (28,29). In the allegory "The Cave," Socrates describes people who have lived their lives confronted with a blank cave wall, observing shadows projected on the wall from objects passing in front of a fire and considering these shadows as reality.

The challenge of this formulation is the distinction between the observer and the observation, paralleling the Heisenberg formulation that the scientist influences observations by measuring physical reality. The observer-observation flaw was later so cemented by René Descartes (1596–1650) that the Cartesian Divide and reductionist world view permeated the deepest core of our academic, social, and intellectual pursuits over the next several centuries

(*30-32*).

The fallacy of this deeply rooted world view dawned in the early part of the 20th century, when scientists like Heisenberg, Einstein, Niels Bohr, and Erwin Schrödinger began to encounter the strange and unexpected new realities of subatomic world. For the first time, they realized that reality is not composed of a multitude of separate objects but rather as an indivisible whole: a network of relationships that included the observer in an essential way. In their struggle to grasp the nature of atomic phenomena, scientists became painfully aware that their basic concepts, language, and their whole way of thinking were inadequate to describe this new paradigm. As physics evolved, the arc from the theory of relativity to principles of quantum mechanics, and finally string theory pointed toward the foundational flaw of the Cartesian Divide.

In fact, further echoes of antiquity (several millennia before Aristotle) bring us the ancient Indian philosophy, which espoused the same notion of oneness that one now encounters in modern quantum mechanics. Modern scientific stalwarts such as Einstein, Bohr, Schrödinger, and Heisenberg, among others humbly acknowledged the philosophical ramifications of their revolutionary discoveries in relativity and quantum mechanics (*33*). Yet the irony is that, despite these evolutions in our understanding of physical phenomena, even today our modern science and validation methodologies have not fully assimilated these foundational principles (*34*) and still suffer with the Cartesian Divide between science, philosophy, and intuitive wisdom (*35*).

In truth, there is abundant evidence of how intuitive wisdom has shaped the facets of science. The concept of carbon tetravalency and the benzene ring developed cautiously and logically in the daydreams of German chemist August Kekulé (1829-1896) (36).

Srinivasa Ramanujan (1887-1920), an Indian mathematician with negligible formal training, made extraordinary contributions to mathematical analysis, number theory, infinite series, and continued fractions based chiefly on intuition (37) . However, the divide between science and humanities is so deep that the mere mention of philosophy alarms a significant proportion of scientists to the level of sacrilege (*35*). Fortunately, the leaders and top institutions are recognizing this fallacy, aptly put in the 2017 commencement address at the Massachusetts Institute of Technology by Apple CEO Tom Cook, “if science is a search in the darkness, then the humanities are a candle that shows us where we’ve been and the danger that lies ahead” (38).

A “renascent” approach: exploring the ideas of the Middle Ages and antiquity

Lets now examine probably one of the biggest lacunae of modern scientific mindset. When asked to identify “scientific giants,” names such as Albert Einstein, Marie Curie, Newton, Charles Darwin, Nikola Tesla, William Harvey, and Jean-Baptiste Lamarck often leap to mind. Although they were undoubtedly giants, a

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curious pattern manifests in that all of them belong to 15th century or later, a period often termed the "modern era." Preceding periods, generally termed either the Middle or Medieval Age (between the 5th and 15th centuries) or Antiquity (before the 5th century), are also labeled by some as "Dark Ages," and derided by many as an age devoid of any scientific developments. This leads one to wonder, "Did the 'giants' not come to earth before the 15th century, did they not make any contributions to science, and if they did, why do we not seek to capitalize on their findings? What happened in the 15th century?"

In a broader historical context, the 15th century can be construed as an inflection point, when scientific advances were catapulted by the consanguinity between European imperialism and capitalism (39). In the ensuing centuries, patronage of imperialism and capitalism culminated in the Industrial Revolution, which ignited a "positive feedback loop" furthering science, capitalism, imperialism, and politics. While these developments transformed the world into our contemporary global order, community, and culture, they should not shroud the enduring innovations of the more distant past such as printing press, astrolabe, abacus, and wheelbarrow, nor either undermine or supplant the intellectual giants and technological advances of the premodern era.

In fact, ancient civilizations were likely so advanced and intricate as to confound our current comprehension, despite our ultramodern scientific tools. Such marvels of antiquity across the globe include the Egyptian Pyramids, Nazca Lines, Machu Picchu, Galgal Refaim, Gobekli Tepe, and Stonehenge, among many others. Full-fledged cities thrived in antiquity, from India's Rakhigarhi (10,000-6,000 BCE), to Israel's Atlit-Yam (6,900 BCE), and Egypt's Thebes (3,200 BCE). Extremely "broad-shouldered" intellectual giants included China's Jing Fang

(78–37 BCE), Cai Lun (50–121 CE), and Zu Chongzhi (429–500 CE); as well as India's Aryabhata and

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Brahmagupta (800 – 600 BCE) and Bhāskara II who wrote *Līlāvatī*

(AD 1150), a treatise on mathematics with detailed chapters on computational, arithmetical, and geometric progressions, plane geometry, solid geometry, and methods to solve indeterminate equations and combinations. Similar examples abound in other, oft forgotten and/or incompletely chronicled world civilizations.

"A glass half-empty?": potential biases of contemporary scientific methods

Despite historical and archeological evidence of our ancient and medieval predecessors' achievements, which seem inconceivable to many modern minds, limited structured endeavors have been undertaken to analyze, catalogue and understand the intricacies of the societies and innovations that inspired and actualized them. Rather than capitalize on these developments and enrich our current knowledge and methodologies, modern thinkers in general experience a surprising and dismaying "knee-jerk" reaction to undermine, refute, and otherwise summarily reject them as anecdotal or "lacking proof," because they were not validated according to the stringent methodologies of modern science notwithstanding the fact that even modern validation methodologies are far from devoid of limitations in both modelling and the extent of applications.

Wisdom of the ancients

Contrary to modern science's reliance on formulating and validating hypotheses only in the language of mathematics, older traditions did implement perception, inference, debates, and testimony to validate their conclusions. Avoiding over reliance on mathematics, these traditions find modern scientific resonances in peer review and "Delphic," iterative approaches that establish consensuses guidelines, practice, and interpretation

(40). If we object that those validation models were insufficiently stringent enough, we must also concede the limitations of our current mathematical validation models. In the final analysis, "a model is a model"; mindful of this meaningful tautology, we should keep an open mind to prior knowledge and recognize that premodern suppositions deserve as stringent exploration as modern scientific advances.

It is not merely a question of ascribing the credit of discoveries but rather capitalizing on their fruits. In 1955, American psychologists Joseph Luft (1916–2014) and Harrington Ingham (1916–1995) proposed the concept of "known knowns," "known unknowns," and "unknown unknowns." Arguably the most difficult to navigate, and the likely location of the greatest buried treasure of wisdom, is the domain of "unknown unknowns." The only way to brighten our horizons is to foray into the terrains of unknown unknowns and systematically retrieve the knowledge gained into the domains of known unknown and, finally, known known (*41*).

It took 100 years to bring the concept of gravitational waves from the domain of known unknown to known known: from 1916 when Einstein first predicted the existence of gravitational waves to their first direct observation in 2015. Concepts such as "Dark Matter" and "Dark Energy" now reside in the domain of known unknowns. Imagine the potential treasure trove of "unknown unknowns" that await exploration from the premodern era? How much could we learn by applying modern computational and other methods of exploration to these ancient and medieval societies and their technological advances? The known medieval and ancient mysteries might be representing merely the proverbial tip of the iceberg. Its beyond imagination to fathom the benefit it can bring to our planet if we relinquish our parochial approach and study, catalogue, and analyze enormous treasure trove of ancient wisdom with the modern computational tools. The value of such exploration transcends our modern focus on “information” to the domain of knowledge; through such endeavors, we are poised to bring humanity its greatest gift, wisdom.

The way forward (and back)

Approximately 100 years after the world witnessed the disruptive transition from classical physics to quantum mechanics, humanity today is now poised on an another and perhaps much larger inflection point. On the one hand we are ravaged by wars, inflation, and pandemic. On the other hand, we have catalogued enormous scientific data (including sequencing the human genome) and have developed potent and robust analytical tools such as Artificial Intelligence, quantum computing, and edge computing. Although we can now analyze “Big Data” and grow our knowledge in a sophisticated manner, we have yet to translate this information into knowledge and knowledge into wisdom, which can inform judgments and decisions (*42*). We tend to overlook the fact that the power of knowledge comes with accountability. As we amass knowledge, it must be balanced with the philosophical and holistic evolution of humankind, avoiding the threats to modern society by our ever-constricting interpretation of politics, religion, nationalities, and civilizations.

Great scientists are mindful of the axiom of Confucius (551-479 BCE) that

“Real knowledge is to know the extent of one's ignorance.” The first facet of modern science is hence the willingness to admit ignorance. Science and wisdom can evolve only via a humble acknowledgment of our many “unknown unknowns.” Efforts have been undertaken to highlight the limitations of our modern scientific approach but have not yet culminated in a succinctly expressed formulation or a comprehensive framework to enable critique and alternative ideas. It is time that we overcome this inertia and embrace an innovative way of thinking, including applying sound scientific methods to the study of ancient scientific, technological, and other discoveries and advances. According to Heisenberg, "Whenever we proceed from the known into the unknown we may hope to understand, but we may have to learn at the same time a new meaning of the word 'understanding'" (*43*).

Conclusions

In summary, there is a need to establish a structured process to expedite and ensure the integration of advancements in the ongoing scientific endeavors. It would be prudent to optimize the pace of scientific developments so that we take time to examine and implement key knowledge gained by our predecessors. We also must institute a systematic exploration into the treasure trove of enormous knowledge and wisdom attained by intellectuals of the premodern era; reflect on the language and limitations of modern science; and introduce a paradigm shift leading humanity into a new science. Such exploration can be spearheaded only by modern legends of the stature of Einstein, Bohr, and Heisenberg, who not only made significant contributions in their disciplines but were also so acutely aware of limits that they yearned to dismantle the reductionist narrow confines of existing paradigms and academic disciplines in their pursuit of wisdom. To lead humankind into the greater discoveries of antiquity, we will need to transcend politics, race, religions, nationalities, and even civilizations. If we can organize and nurture such a congregation of academic rebels, whatever the world has seen in the name of development so far may turn out to be a mere prelude. Such an assembly of intellectuals is required to embody the rigor of a scientist, humility of a saint, wonder of an explorer, and above all the valor of a warrior to break through the limits of knowledge and achieve, as Jiddu Krishnamurti (1895-1986) coined it, "freedom from the known" (*44*).

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