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The Scientific Method is Dead? Addressing the Inadequacies in the Scientific Method

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INTRODUCTION "*What we need is imagination … we need to find a new view of the world*" Richard Feynman (1959)

With those words, the Nobel Laureate Richard Feynman introduced his new concept of nanotechnology during a theoretical physics lecture at California Institute of Technical (CalTech). This was revolutionary, and prescient, for now, nearly 50 years later, the scientific community is realizing just how prophetic that statement was. Scientists throughout the world are becoming aware of the limitations of the scientific method during this extraordinary era of scientific discovery. Some have been bold enough to whisper behind closed doors "The Scientific Method is Dead… Long Live the Scientific Method". Just what is prompting this heresy?

As we look at Science, it is necessary to first define what is meant by Science and what is its role in the advancement of the species *homo sapiens*. The Oxford English Dictionary defines Science as ". . . study that relate(s) to the phenomena of the material universe and their laws." While this definitive, it is not very pragmatic. I would propose a simplistic and functional approach - Science is *the attempt to describe the world we live in*. And the purpose of Science is *to provide the means to interact with the world we live in – in a consistent manner that provides predictable results to conduct the daily process of living*. While there is much Science which appears to be conducted "for the sake of Science alone", it is astounding just how much of this "pure science" results in practical benefit decades later. Understanding quantum mechanics has no practical application at this time, yet decades from now there is the promise of revolutionary new applications.

Since the dawning of mankind, there have been attempts to understand our world and cope with the challenges. Early during the Classical period (Greek and Roman), scholars such as Aristotle, Archimedes, etc developed the method of "observation" – carefully documenting and attempting to explain the known world. The 'tools' were primitive, and mainly limited to observing, although the beginnings of measurement tools such as rulers, weights etc and methods such as mathematics, geometry and simple physics emerged. These sufficed to the next great revolution – the Renaissance. To observation was added "phenomonolgy" the grouping and classification of similar observations that described specific observations, by scientists such as Michelangelo, Leonardo DaVinci, etc, such as the flow of fluids (hydrodynamics) or methods such as variables and fractions and algebra and calculus. These scientific methods persisted for centuries, until the Age of Enlightenment, when another surge of discovery occurred when Newton, Boyle and others ushered in the era of "experimentation" – taking known phenomenon and subjecting them to experiments which tried to duplicate the observed phenomenon. They constructed new instruments, like microscopes, telescopes, etc and created new methods of measurement. As the Industrial Age started, the beginnings of the Scientific Method as we know it today began to emerge. By understanding how experiments could prove various phenomenon, the next step was to invent hypotheses that would explain and predict the phenomenon and then be proven by experimentation. This methodology continued to be refined, until today the gold standard of scientific inquiry is the prospective, randomized, double-blind study, laden with statistical analysis that quantifies the accuracy of the hypotheses to predict outcomes. While the Scientific Community at large has been using the Scientific method for nearly a century to move from the Industrial Age to the Information Age, healthcare practioners have just recently accepted this method and begun implementing it as "evidence-based Medicine". The irony is just as healthcare practice has finally become truly scientific, the Scientific Community has begun to realize that we are in the midst of yet another revolution, one in which the Scientific Method is not adequate to explain the world we live in. This does not mean that we will throw away the Scientific Method, rather it is time for the next step in the Evolution of Science, which requires yet the next methodology to help explain those phenomenon which the Scientific Method cannot reveal and to extend our species ability to proceed to the new horizons is Science. A simplified summary of the progress of the scientific method is illustrated in figure 1.

In looking at a summary of the progress in scientific methods, Thomas Kuhn in his book "The Structure of Scientific Revolutions"(1), posits that a crisis in science occurs when we begin to understand our world at such a greater depth of knowledge, that exceptions-to-the-rule are discovered and a crisis is created because the rules can no longer explain everything on a given subject. This requires a new methodology that would explain not only the existing phenomenon, but also the exceptions. Today this is seen in areas such as

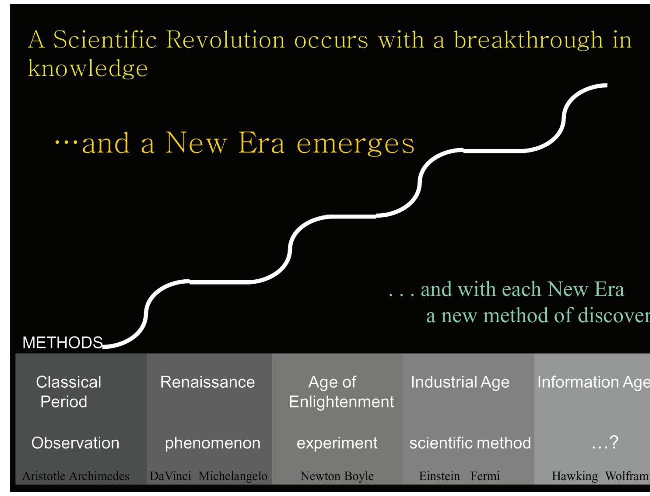

Figure 1: **Simplified summary of the progress of scientific revolutions**

quantum mechanics, black holes, dark matter, systems biology, and even the human genome itself. Alvin Toffler in his book "The Third Wave" (2) gave great insight into these processes of change, and even coined the different Ages which we refer to today – the Agricultural Age, Industrial Age and the Information Age. It appears that we are evolving into yet another Age and for want of a better name, I propose the "Biointelligence Age"(3). The reason is that the scientific discoveries that are making the largest (but not only) impact upon our understanding of the world are the biological (Life) sciences, and that the result (functional importance) is that the new sciences are making our world 'smarter' – devices and methods which actually have a low level of "intelligence" and can initiated some automatic behaviors, such as sensors, computers, integrated chips – hence the derivation of BioIntelligence Age. There is a fundamental difference between the physical (material world) and the biological (living) world. The biological world continues to evolve and adapt on its own – it is an inherent property of biology. This has required understanding the world at a higher level of complexity, beyond that which currently can be understood. Therefore, observing Nature (biology), we can discover phenomenon which we can imitate (biomimicry, bio-inspiration, etc) and solve problems which were previously too complex.

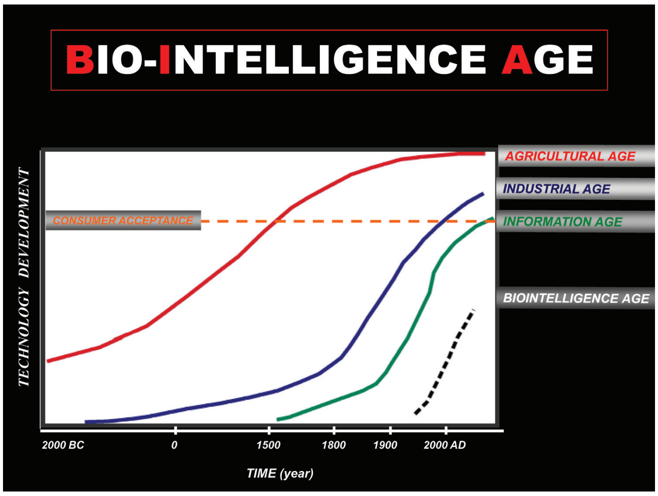

Figure 2: **Progress of the Ages of Science (reinterpretation of Toffler)**

Looking at a graph of the progress of a revolution (figure 2), which is a reinterpretation of Toffler's three Ages, it is apparent that there is a long tail of 'discovery' before a tipping point is reached where the new discovery is accepted and understood enough that the 'revolution in Science" begins. At this point the science rapidly gains acceptance and products are developed. There comes a time when the new science gets accepted by consumers at large, and then the discoveries become incremental (not revolutionary) and simple changes are made to existing products. The cell phone is an example. There have been cell phones since the early 1970's but there have been no new discoveries (the cell phone of today just has more bells and whistles, cameras, etc). This could be said of the Information Age in general – no new discoveries in over a decade – every "new" product is simply an iteration or combination of the existing technologies with some new features. This coincides with the feeling of the leading scientists that the Scientific Method cannot provide the methodology to discover the necessary revolutionary technology. As a matter of fact, the Scientific Method was designed mainly to *prove* an already existing new discovery. Hypothesis driven research has at its core the purpose of proving whether a new discovery is actually valid.

What are some of the limitations of the scientific method? First and foremost, it cannot be used to discover new solutions to extremely complex problems, although it can validate the new discoveries. Secondly, not all hypotheses can be tested with the gold standard of the Scientific Method – the prospective, randomized double-blinded trial. There has never been a study conducted using the Scientific Method which has proven that jumping out of a disabled airplane with a parachute is better than jumping out without a parachute or by crashing with the airplane (the control arms of the study) – there were no volunteers to be in the control group that jumped out of an airplane without a parachute. Yet the merits of the parachute are obvious and accepted.

CHARACTERISTICS OF A NEW METHODOLOGY. "*Imagination is more important than knowledge.*" Albert Einstein

One of the greatest deficiencies of the Scientific Method is the inability to generate new ideas - there is no method by which the hypothesis is derived. Looking at the progress of scientific discovery, it is noted that first there was observation, then collating observations into phenomenon. Next phenomenon were investigated using experimentation to reproduce the phenomenon. And today the experiments are codified by beginning with a hypothesis about the experiment on the phenomenon and observations. In short, each revolution it science methodology occurs at the "front end" (figure 4), which at the present time is where hypotheses are generated, which can be proven by experimentation. The Scientific Method will not go away or be replaced – it will remain the cornerstone of proving what we hypothesize (imagine). Where the new revolution must occur is to somehow instantiate the processes of imagination, intuition, creativity, etc into the scientific methodology.

Investigating biological phenomenon has revealed an important clue to what will be required of the new methodology of science – a systems approach. There are many great hypotheses that have been able to demonstrate new knowledge about our world, how-

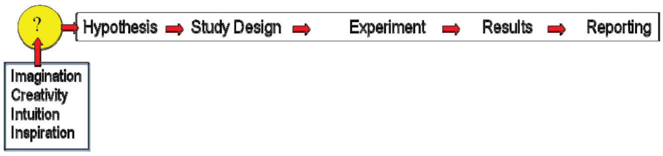

Figure 3: **The structure of the Scientific Method**

ever these are simple compared to the rapidly accumulating knowledge. The level of complexity of our knowledge now has lead to hypotheses which combine a number of known phenomenon. However, due to this new level of complexity, the results do not match the hypothesis. The reason is that as the complexity grows, *emergent properties* occur. This is similar to the common phrase "the whole is greater than the sum of its parts". Given two known fundamental proven facts which logically lead to a predictable conclusion, when they are combined an entirely new result occurs. This is common in biologic systems and is explained by the processes such as self-replication, self-assembly, mutation, feedback loop control, etc. These processes lead to unpredictability and result in the new, emergent properties.

POSSIBLE DIRECTIONS FOR THE FUTURE. *"We have it in our power to begin the world over again."* Thomas Paine, ("Common Sense", 1776)

There is a growing sense within the scientific community that a new methodology will be emerging. However, beyond those studying complexity, there is precious little to indicate what this direction might be. Stephen Wolfram, the heir apparent to Steven Hawkins, in his recent tome "The New Science" [4] addresses this dilemma, and suggests that a major component of the new methodology will involve mathematical modeling and simulation (M&S). In fact, most scientific disciplines have already incorporated M&S into their investigations. It is common practice create a computer model of the new device, drug or process before actually constructing the real entity. In addition, this computer model is subjected to numerous tests, variations, etc to determine if the computer model is optimized. These computer-based simulations are referred to as virtual prototyping, virtual testing and evaluation, etc. All of this is completed before building the first prototype, which usually is very close to the finished product. The use of M&S provides the opportunity to conduct hundreds or thousands of 'trials' to determine the best solution. Interestingly, often a better result 'emerges' as result of the simulation, one which could not be anticipated ahead of time.

One of the reasons is that the computer programming that is being developed, referred to as computational analytics, allows millions of variations to be simulated in a very short period of time, to optimize the final product. One of the other components of the new science is multi-disciplinary approach to a problem. Figure 4 is a Venn diagram that illustrates how today's science requires many different disciplines to solve a problem – from each of the three major science disciplines – life science (biology), physical science (including engineering) and information science. Is the human genome project a biological, information or engineering project? Actually it requires all of the disciplines to solve such a complex problem. And as

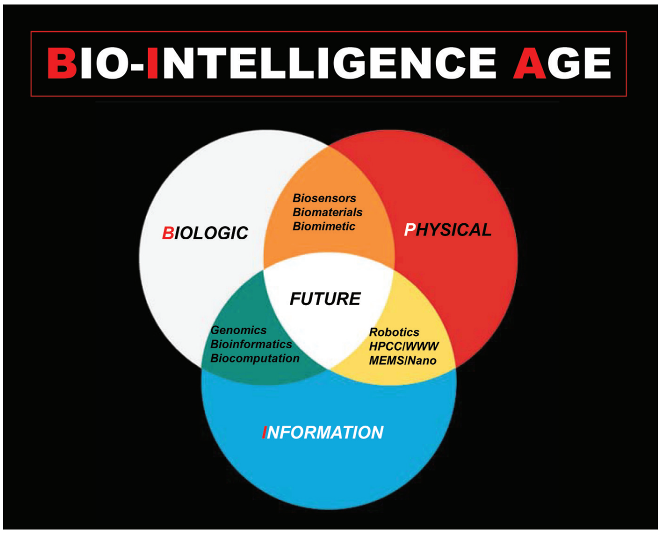

Figure 4: **The multi-disciplinary approach required for new discoveries**

knowledge exponentially increases, the need for multi-disciplinary research grows.

The yet to be discovered component of the new science remains that of the imagination – how is intuition, creativity, etc generated in order to develop a new hypothesis. The answer will likely emerge as research into the brain progresses and mysteries such as consciousness, cognition and other complex processes yield to the probing scientific mind.

Predicting the final discovery of a new scientific methodology is beyond current knowledge, but the fact that scientists are seriously pursuing alternatives to the Scientific Method demonstrates that there will likely be a solution – which will emerge!

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