SCIENTIFIC DISCOVERY AND ITS ROLE IN SPORTS SCIENCE

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Commentary
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Abstract:

Scientific discovery is about a search for the Truth, for the consistent and predictable in how the universe works. Using a particular method of inquiry, the scientific method, and with acknowledgement of the inherently self-correcting nature of science, scientific inquiry moves forward incrementally to ever closer approximations of the Truth. This paper reviews the history of scientific inquiry, the methodology of the scientific method, including the necessity for hypothesis testing and development of the probability that a particular answer is a closer approximation of the Truth than previous answers have been. It also discusses some of the pitfalls of scientific inquiry, and areas in which the search for Truth may be corrupted.

Key words: *scientific method, hypothesis, paradigm*

Introduction

Truth! One of the continuing quests of humanity is for the Truth. Although lower in Maslow's hierarchy of needs than breathing, water, food, personal security, and meaningful interaction with loved ones, Truth (knowing what is real, dependable and predictable) is near the top of any list of human needs. Scientific discovery, as a unique pathway to discovering the Truth, is a critical vehicle for accessing Truth in modern technological societies. Indeed, the search for Truth, and the systematic organization of experiences, may be what lead societies to become technological. Because of the inherently self-correcting nature of science, the essence of Truth can evolve as more and/or better data become available, allowing us to discard what was once a useful point of view in favor of better approximations of the Truth. Thus, seeking Truth is a fundamental quality of human behavior and is fundamentally important to the functioning of society. Seeking Truth also represents the essence of science, although the search for Truth goes across other avenues of Truth seeking – intuitive, religious, empiric, philosophical and scientific (Table 1).

Historical roots

For much of human history, Truth was defined and delivered by religious, cultural or philosophical traditions, through direct revelation by a Deity or prophet, through collective cultural wisdom such as that passed down from Father to Son and Mother to Daughter, through what Immanuel Kant called 'pure reason' or through what Buddhists would call 'meditative insight'. These versions of the Truth were essentially defined in the writings of the scriptural documents of the world's great religions, and from the giants of classical civilization such as Plato, Aristotle and Rene Descartes ("I think, therefore I am). Although Socrates and Aristotle started the tradition of empirical observation (which

Table 1. Searching for Truth in many avenues of human experience

Truth is a central concept in virtually all religious traditions:
1. "I am the way, the truth and the life, no man cometh unto the Father but by me", John, 8:32.
2. "You shall know the truth, and the truth shall make you free", John, 14:6.
3. "Truth is an eternal duty", The Mababharta
4. "Three things cannot be long hidden, the sun, the moon and the truth", Buddha.
5. "Oh, you, who believe: have fear of God and be among the Truthful", Quran, 9:119.
6. "Peace, if possible; Truth at all costs", Martin Luther
7. "All the religions of the world, while they may differ in other respects, unitedly proclaim that nothing lives in this world but by the Truth", Mahatma Gandhi.
8. "Speak the Truth, do not yield to anger, give if thou are asked for little; by these three steps thou wilt go near the gods", Confucius

Truth is a central concept of philosophical systems:
9. "The least initial deviation from Truth is multiplied later a thousand fold", Aristotle
10. "The object of the superior man is Truth", Confucius
11. "Every Truth has two sides, it is as well to look at both, before we commit ourselves to either", Aesop
12. "The words of Truth are always paradoxical", Lao Tzu
13. "Even if you are a minority of one, the Truth is the Truth", Mahatma Gandhi

Truth is a central concept of literary thought:
14. "The Truth is rarely pure, and never simple", Oscar Wilde
15. "Rather than love, than money, than fame, give me the Truth", Henry David Thoreau
16. "Beauty is Truth, Truth is beauty, that is all ye need to know", John Keats
17. "Once you eliminate the impossible, whatever remains, no matter how improbable, must be the Truth", Arthur Conan Doyle
18. "There is no greatness where there is no simplicity, goodness and Truth", Leo Tolstoy

Truth is a central concept of political thought:
19. "We hold these Truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty and the pursuit of Happiness." U.S Declaration of Independence
20. "It is error alone which needs the support of government. Truth can stand by itself", Thomas Jefferson
21. "He who knows nothing is closer to the Truth than he whose mind is filled with falsehood", Thomas Jefferson
22. "A nation that is afraid to let its people judge Truth and falsehood in an open market is a nation that is afraid of its people", John F. Kennedy
23. "For my part, whatever anguish of spirit it may cost; I am willing to know the whole Truth, to know the worst and provide for it", Patrick Henry
24. "Half a Truth is often a great lie", Benjamin Franklin
25. "The Truth is incontrovertible. Malice may attack it, ignorance may attack it, but in the end, there it is", Winston Churchill
26. "I am a firm believer in the people. If given the Truth, they can be depended on to correct any national crisis. The great point is to bring them the real facts", Abraham Lincoln

Truth is the most fundamental grounding of legal traditions:
27. "Do you swear to tell the Truth, the whole Truth, and nothing but the truth, so help you God?"

Truth is a common element of popular culture:
28. "The Truth is out there", the X-Files
29. Of investigative journalists who badger their interviewees for 'the Truth'.
30. Of the so-called conspiracy theories, which widely assume that the Truth is being distorted or hidden by some sort of authority figure.

The search for Truth is, and has been a common, consistent and essential element of scientific inquiry:
31. "All Truths are easy to understand once they are discovered, the point is to discover them", Galileo Galilei
32. "To myself, I am only a child playing on the beach, while vast oceans of Truth lie undiscovered before me", Isaac Newton
33. "The pursuit of Truth and beauty is a sphere of activity in which we are permitted to remain children all our lives", Albert Einstein
34. "Anyone who doesn't take Truth seriously in small matters cannot be trusted in large ones either", Albert Einstein

is a central technique in scientific inquiry), they are mostly remembered as 'reasoners'. Even Pythagoras, the mathematician, was as much a mystic in search of the mysteries of life as of mathematical proofs. The combination of Aristotle's ideas with scholasticism (the dogma defending method of critical thought that grew out of medieval Christian monasteries which did a reasonable job of preserving classical knowledge during the Middle Ages) probably delayed later growth of observational science.

Beginning in ancient Babylon and Egypt, continuing through the grand intellectual periods of China and the Arabic world (during which Europe was mired in the middle ages), and emerging in Europe in the 15th century Renaissance Italy, a tradition of *empiricism* (knowledge that comes from sensory experience) began and matured into what we recognize today as the *Scientific Method*. Much of the growth of empirical, observation-based science depended on improved or completely new instrumentation designed and built by early scientists/artisans. They combined a systematic approach to observation with their own technological innovations and craftsmanship to achieve fundamentally different and more accurate observations than were possible with the unaided human senses alone. For example, central observational discoveries in astronomy and biology would not have been possible had Galileo not recognized the value of the telescope to test the observational hypothesis of Copernicus of a heliocentric universe, as opposed to the geocentric universe of Ptolemy. Similarly, had Antonie van Leeuwenhoek not developed the microscope, which revealed a previously unseen *microscopic* world coexisting and co-locating (on our skin and even inside our own bodies) with our *macroscopic* world, our view of biology would have been fundamental more short-sighted.

Central to the emergence of the Renaissance was the often glaring mismatch between the Truth (vigorously defended by the Church), and the observations being made by a remarkable series of polymaths, including da Vinci, Copernicus, Galileo, Michelangelo. The discovery of the New World (which in the ‘flat earth’ view simply was not supposed to be there) added more fuel to the Renaissance fire. Later work by William Harvey, Newton, Darwin, Hubble, Einstein and (even more recently) Watson and Crick have progressively refined our view of the universe. These findings challenged much of the accepted Truth, associated not only within the Catholic Church and other religious traditions, but also within ancient wisdom represented by Plato, Aristotle, Galen, Ptolemy and Descartes.

Accessing the Truth by empirical means is limited by our sensations and perceptions (observational ability). To Copernicus, who could only watch and measure the stars move with his eyes, the empirical detail available from contemporary space telescopes that can see with remarkable magnification, in wavelengths not visible to the human eye, and from locations remote from the Earth, would border on the magical. As of today (2016), the Scientific Method still depends on amplification of our ability to make inference through perceptions. Perhaps there are vehicles for allowing systematic approaches to the Truth what would be as hard to conceive for us as a gamma ray orbital telescope would have been for Copernicus. Only time will answer this for us.

Roger Bacon, who can arguably be called the father of the Scientific Method, made his foundational arguments about the necessity for *repetitive observations* and *experimental verification* with carefully *described methods*. This led to the central concept that Truth can never be absolute, but should be described in terms of probabilities. This fostered the development of scientific *skepticism* (which denies or doubts the possibility of the certainty of knowledge), and gave birth to an ever-growing and maturing framework of observational and experimental methods of accessing Truth. Central to this entire process was the recognition that Truth is not always universally true, as in “my Grandfather said this is so”, or “the Bible tells me so”, but depends on the ability to improve our understanding by gathering and integrating ever more information. This is not to say that other avenues (religious, philosophical, cultural) of acquiring the Truth are not of great value. Science simply recognizes that the nature of Truth is based on the totality of what we know and can observe, thus being uniquely self-correcting.

The Scientific Method

Just as the ability to gather data evolved with mathematics and technological innovation, the concept of how to approach a search for the Truth has also evolved. The *Scientific Method* can be described as the process by which science (a certain way of searching for the Truth) is carried out. The goal of scientific inquiry is to obtain knowledge in the form of *testable* explanations that can predict future empirical (observational or experimental) observations.

The Scientific Method is iterative; building continually upon previous knowledge, on Newton’s concept of ‘standing on the shoulders of giants’. At the beginning, science may rely on simple observations (e.g. shepherds watching the pattern of stars – including the strangely moveable stars – in the sky, and trying to explain what they saw). Sometimes observations depend on *serendipity* (making a one-time observation by pure chance, often while looking to explain something else, and then having the sagacity – wisdom – to place the observation into context with what else is known; hence the truism “chance favors the prepared mind”). Science then relies on developing a provisional explanation for observations (whether designed or planned). The term for developing a provisional explanation is called *forming a hypothesis* (best guess is probably more accurate), which makes predictions of what should happen in a certain situation (*if what we think is true, what would be the next thing to* *happen?),* and then making observations/experiments to test the accuracy of the predictions. Statistical analyses define the probability or chance (or likelihood in the jargon of newer inference-based statistics) that the observed results happened for the reason you expected them to happen, and if the magnitude or size of an effect/result is likely to recur if similar conditions are repeated. The essentially skeptical nature of scientific inquiry argues that regardless of any set of results, there can never be absolute certainty regarding the Truth. What you get is progressively better approximations of the Truth and reductions in the magnitude of uncertainty about a topic. In essence, the use of the Scientific Method can lead only to support or non-support for hypotheses, *never proof.* Even the best supported hypothesis, for example Newton's laws of motion, required modifications as better evidence became available, often only because of technological innovation.

Science is also geared toward seeking simplicity. One of the ultimate tests of any set of scientific observations is whether they are parsimonious (simple). The concept of Occam's Razor is never far from the vocabulary of science. Sir William of Ockham, a 14th century priest and scholastic (one of those scholastic guys who held back the progress of empirical science) suggested that if there were several ways to explain a set of observations, the most simple (parsimonious) was the most likely to be true. You have to have the verbal 'flip-flop' skills of a contemporary politician to use science, because "changing your mind" is dependent only on the next set of data. In science uncertainty is a normal condition and you will always, eventually, change your mind.

Science versus religion, politics and business

If a hypothesis is supported, systematically, over a number of observations or experiments, the state of understanding about that topic can be expressed as a *theory*. Theories are nothing more than well-supported hypotheses. There does not seem to be a "magic number" of supportive studies required to convert a hypothesis into a theory, some hypotheses just seem to increase in stature until suddenly it is a theory. Science has an extremely strong track record for producing theories that ultimately improve the human condition through the technologies, methods and treatments that emerge. Science is also very good at showing what does not work so well. Consider the advances in medicine in just the last century to understand how our viewpoints can change with better data (Frosch, 2007; Pierach, Wangensteen, & Burchell, 1993). Unfortunately, science has also historically been seen as a threat to the status quo, particularly in matters of religion (which argues that revealed Truth is universally unchanging), politics (which argues that Truth is always negotiable) and business (which often finds the Truth inconveniently getting in the way of a short-term profit). This has resulted in extremely strong resistance to even the most well-founded scientific theories; resistance that is as evident today as when the Pope forced Galileo to recant his views of the heliocentric universe.

A contemporary example of such strongly supported, yet strongly resisted theories might include the theory of evolution. The theory of evolution has been supported by observations and experimental studies spanning the last 150 years, but still is not fully accepted. The resistance is primarily attributable to evolutionary theory contradicting religious concepts of a discrete creation by a Diety, over a very short period of time, with humans uniquely, and properly, situated at the pinnacle of creation, versus the concept that life has evolved over a very long period of time, and that humans are just another product of the evolutionary process. Another contemporary theory would be that of global warming secondary to the impact CO_2 accumulation from human activities. Increasing atmospheric CO_2 concentrations are clearly observable. So is a steady increase in global temperature over the last century or more. Both are very likely attributable to fossil fuel use and deforestation caused by humans. Although overall global warming is the net result, the theory also predicts that weather may become more extreme locally, including cold weather. This theory faces disproportionate resistance despite the growing evidence in its support, primarily because its implications could be costly for industries in both developed and developing countries. Theories defining the relationship between tobacco smoking with cardiovascular disease and cancer risk were resisted for decades by a powerful one-two combination of tobacco industry lobbyists (often with their own paid-for-scientists) and tobacco grower friendly politicians. Fortunately, over the last decade, the sheer weight of evidence has forced recognition of the harmful health effects of tobacco use, and the institution of anti-smoking laws in much of the developed world. Unfortunately, the same business forces have promoted tobacco use in the less scientifically conversant developing world. Profit is, after all, profit, and Truth should not get in the way of profit!

Rules of engagement

Science differs from other ways of accessing the Truth in three unique ways. First, science absolutely relies on the process of forming and testing hypotheses. Anyone can have an idea about what causes something to occur. To use science, you have to be willing to test the hypothesis. And, most critically, you have to be just as satisfied if the test shows that your hypothesis is wrong. You are looking for Truth, not validation of your rightness. Second, science relies on verifiability. You have to be comfortable having someone else testing your hypothesis, and showing that you are incorrect. Science is a process which recognizes that progress comes from a process that can reject or modify incorrect ideas. Third, science is self-correcting. Although some concepts are very persistent, few scientifically derived findings remain 'true' forever. If a theory stands the test of time over a very large number of attempts to show that it is wrong, the hypothesis-theory can become a *law*. But even a well-established scientific law can be cast aside under the weight of new evidence. For example Newton's laws of motion still work remarkably for explaining most of what we observe in the physical world, 400 years after their emergence. But, we now know that Newton's laws are unsatisfactory at the level of the very small (atoms) and very large (solar) systems. Indeed, Einstein used changes in the orbit of the planet Mercury to demonstrate that his theory of relativity (a hypothesis at the time) better fit the data about how Mercury moved than did Newton's laws of motion. Even the venerable Einstein had to wait a couple of decades before other scientists were able to make observations during a solar eclipse that supported his prediction of gravity bending light waves, a critical prediction in his theory of relativity. If one thinks that Truth has finally been achieved, that all the information about a topic is known, that there is nothing to be further discovered about an issue, then one simply is not prepared to do science.

On the other hand, religion, which is one of the classical methods of seeking Truth, believes that new evidence is not necessary, that much (if not all) all of the relevant evidence has already been 'revealed'. One only has to read Hebrews 11:1 in the Christian New Testament "now faith is the substance of things hoped for, the evidence of things not seen" to understand that the fundamental approach to seeking the Truth is through faith in the correctness of scriptures, delivered (or inspired) by a Deity. While this is a specific example from the Judeo-Christian tradition, the same basic idea is pervasive in religious documents from many traditions. While not minimizing the wisdom provided in the writings of religious traditions, the fact is that the fundamental approach to seeking Truth is inherently different from that of science. Science absolutely relies on the observable (or at least the potentially observable). It does raise a larger question of whether science is capable of answering all questions, even ones that cannot be answered today. Are there questions beyond the reach of science that can only be addressed by non-empirical methods (e.g. faith in the correctness of inspired texts, the non-linear possibilities of meditative insight)? If scientific 'proof' is impossible, it seems likely that there are also questions that cannot be answered using the method of testing hypotheses. However, observational ability changes greatly over time. For example, would van Leeuwenhoek have understood the possibilities of a scanning electron microscope?

Scientific versus technological

Because science is both a driver of technological development, and facilitated by technology, there is a tendency to equate the term *scientific* with *technological*. That is simply not the case. *Scientific* refers to a *method* of thinking, a *way* to trying to understand the world, an *avenue* for approaching the Truth. It has very little to do with the use of a sophisticated piece of hardware. Science sometimes is helped by technology, because technology can make better observations possible. But, in many cases, science can be done with only a minimum of technology, or none at all. For example, in sports science research, you could learn a lot about the exercise training response by simply having someone run a certain distance as fast as possible, giving them a training program that you hypothesize is superior to some conventional (or control) training program, and seeing how much faster they run after a reasonable period of training (Foster, Daines, Hector, Snyder, & Welsh, 1996; Sylta, et al., 2016). The most advanced technology required might be a good stopwatch or perceived exertion scale. Alternatively, you could perform a muscle biopsy, make measurements of molecular markers of gene expression and gauge the rate of synthesis of new proteins that should be associated with running faster (Yeo, et al., 2008). The two approaches are quite different in terms of technology, but equally *scientific*. Although your understanding of the training response might be much more complete after using the more technologically sophisticated approach, the fundamental answer to your question would be the same, although one always has to be aware of the signal-to-noise ratio when complex technologies are used to answer questions.

One of the overriding elements of the scientific method, in some ways superseding both theories and laws, is the concept of a *paradigm*. Well developed in the classic book *The Structure of Scientific Revolutions* by Thomas Kuhn (1962), the paradigm can be thought of as the fundamental way of thinking about scientific data; indeed, the paradigm often defines the way in which scientific questions are asked. Because of the pervasive nature of a scientific paradigm, changes are very often hard to make. In Kuhn's view, paradigm shifts are equivalent to political revolutions in terms of how strongly the protagonists and antagonists interact. In sports science, for example, the recent battle between the cardiovascular/anaerobic model (Mitchell & Blomqvist, 1971) and the central governor model (Noakes, St Clair Gibson, & Lambert, 2004), or between the central governor model and the psychobiological model (Amann, et al., 2008; de Koning, et al., 2011; St Clair Gibson, et al., 2006; Tucker, 2009) are good examples.

Early proponents of ideas that challenge an existing paradigm are often treated badly, with derision and (more importantly) with difficulty in publishing their data or securing funding for their research. One classical example is the concept of a heliocentric, rather than a geocentric solar system. Nicholas Copernicus first articulated the heliocentric hypothesis in 1543. However, he actually delayed publishing his results until just before his death, because he knew he would be branded a heretic by the Church. Galileo, the central figure in terms of making the early observations (in 1610) in support of the Copernican hypothesis, had enormous trouble with the Church, and was at least for a time obligated to recant his viewpoint that the Copernican model was correct. The Church burned heretics at the stake back in those days! Darwin reportedly delayed publishing his defining work, *On the Origin of Species by the Means of Natural Selection* for some years because he knew the results would be controversial and strongly resisted by the Church. Challenging paradigms is dangerous business.

In more contemporary times, the view that atherosclerotic disease was inherently progressive, and that once a person had atherosclerotic cardiovascular disease, they were essentially doomed to a progression of symptoms, presented the dominant paradigm relative to our understanding of cardiovascular disease for many years. Many drug therapies, and even bypass surgery and angioplasty (with or without stents), are grounded in the fundamental assumption that the underlying disease cannot be treated effectively. The lesions can be squashed, the diseased artery can be bypassed, the demands of the heart on the coronary circulation can be decreased, but the fundamental atherosclerotic lesions were supposedly doomed to worsen progressively. An early proponent of the concept that atherosclerotic lesions were malleable and that the atherosclerotic processes could be reversed was Nathan Pritikin (Pritikin & McGrady, 1979). In the 1970's, Pritikin (a self-taught innovator, who was not medically trained) suggested that if the risk factors for atherosclerotic disease (particularly serum cholesterol) were changed in a dramatic way, that cholesterol deposition in the arteries could be reduced, effectively reversing the atherosclerotic disease process. Pritikin was not treated well. In fact, he was widely viewed as something of a 'crackpot'. I can remember visiting Pritikin's Longevity Center in 1979, as part of a tour organized for attendees at the American Heart Association meeting. We were served a meal, about which one of my colleagues (a co-author of this text) who happened to be a vegetarian, remarked "I'd rather have heart disease than eat like this". Later, Pritikin took the stage and announced to the audience his goal of "getting enough funding to do research and *proving* that this approach works". In the moment, he lost much creditability, as the skeptical nature of science pretty well dictates that *proving* anything is basically not possible. Later, of course, basic science research about cholesterol receptors by Brown and Goldstein (1985) (who earned the 1985 Nobel Prize for medicine), translational work on the effect of cholesterol lowering drugs on the course of atherosclerotic disease, and applied clinical research (Hambrecht, et al., 1993, 2004; Haskell, et al., 1994; Ornish, et al., 1998) demonstrated (not proved) that the concept that atherosclerotic disease could be reversed was fundamentally correct. Accordingly, although many of the treatment strategies for coronary heart disease are still grounded in the concept that atherosclerotic disease is inherently progressive, the presence of lifestyle modification recommendations and the widespread use of statins and exercise in the population attests to the reality that the paradigm is changing.

Historically, fatigue during exercise was thought to be attributable to a failure of the muscle to be able to respond to stimulation, secondary either to the accumulation of waste products produced during muscle contraction or to depletion of metabolites necessary for generation of ATP necessary to drive muscle contraction. However, a variety of observations relating to what has come to be called 'pacing strategy" (Foster, et al., 2012) demonstrated that muscular power output in humans almost never falls to zero during even the most fatiguing exercise, as it does in tissue preparations and denervated limbs. Lead by the observations of Ulmer (1996) that spontaneous exercise behavior could be described by a concept called 'teleoanticipation', which required both an anticipation of how hard to perform a task and feedback from the periphery about the magnitude of homeostatic disturbance resulted in broader concepts such as the central governor theory (Noakes, et al., 2004), exercising with 'reserve' (Swaart, et al., 2009), and the 'anticipatory-feedback model' (Tucker, 2009). These hypotheses have supported the theory that there is a two-way dialogue between the conscious brain (where activity is conceived and organized), and feedback from the muscles (which act semiconsciously, to modulate the central motor drive). Interfering with the feedback mechanism(s) can lead to a short term increase in muscular power output, at the expense of a more profound disturbance of homeostasis in the muscle, conditions more like that described in the classical work of muscle fatigue in the absence of an intact nervous system (Amann, et al., 2008). Thus, the paradigm of fatigue has evolved from a unidirectional, muscle condition dependent decrease of muscle power output into a tightly integrated, two-way signaling dependent process, which may depend on post-activation potentiation as a confounder of fatigue (Del Rosso, et al., 2016). But, the process has taken 30 years, and has involved an appreciable amount of conflict amongst proponents of different views of fatigue.

Types of science

In a general sense, scientific investigation can be fractionated into three broad categories. All are science, all rely on empirical observations, on forming hypotheses, on making predictions about the outcome of subsequent observations or experiments, and on using statistical tools to decide whether a hypothesis is supported or not supported. All are absolutely dependent on the self-correcting nature of science to allow evolution of theories and laws. All recognize that achieving 'proof' (absolute certainty) is not possible.

In the biological sciences, scientific endeavor can be thought of as a continuum of atom-molecule-cell-tissue-organ-organism-population. Any of the subsequently discussed varieties of science can be concerned with any level of organization. *Basic science* is more often concerned with the behavior of units at the cellular level or smaller. *Translational science* is more often applied at the tissue-organ level of organization. *Applied science* is almost always concerned with events occurring at the level of an organism-population. Basic science is about the process of discovery, about acquiring comparatively isolated (some people say *reductionist*) sets of information, without regard for whether the information has any particular short-term usefulness. The process of basic science without an underlying theory was referred to as "Chaos in the Brickyard" (Forscher, 1963) in one of the classic editorials about the process of science. Countering this notion is that other varieties of science absolutely depend on the fundamental knowledge created by the process of basic science. However, it is sometimes hard to anticipate what is likely to become useful and what will become isolated information, unlikely to be of further use. Translational science is a stage between basic and applied science. It is probably fair to think of translational science in terms of 'bench to bedside' or 'test tube to track'. Translational science most often works at the level of tissue-organ, but can more properly be thought of as an approach that tries to find the context, and the likely connection between basic and applied science. Applied science is about finding how information discovered at the level of basic and translational science fits into the behavior of an organism (a person) or a population (a group of people).

Within the continuum of science, we have to consider relative merits of observational vs. experimental (e.g. interventional) science. Observation requires a certain amount of good luck (comets running into planets, elite athletes achieving world records, patients catching a rare disease), but have the advantage of occurring 'in context'. Experimental studies (including meta-analyses, systematic reviews and *randomized clinical trials* that are the hallmark of "A level" evidence in medical science) are valuable because of their ability to control extraneous variables. But, with many interventions in the real world (for example the frequency, intensity and time of an exercise program), it is rare that only a single variable is operating. All things being equal, experimental studies are stronger evidence, because there is a certain amount of "control", but this often happens at the expense of a real world context. Likewise, particularly in the medical sciences, one has to be aware that *prospective* studies (studies you planned to do from the start) typically generate much stronger evidence than *retrospective* studies (data you happened to have which allowed a question to be addressed). Published studies can even be combined, using carefully defined statistical tools into 'meta-analyses' which allow an increase in the statistical power of isolated individual studies.

A brief strategic detour and humorous diversion

Science is done by scientists, people who use a rather specific way of seeking the Truth about how the universe behaves. Scientists are people who make observations, formulate hypotheses (guesses) about what is happening, make predictions about what they are going to see next, perform observations or conduct experiments to test the accuracy of their hypothesis-driven predictions, and then analyze the derived data to define the probability that what they saw is indeed what they think they are seeing. That is concisely true, but it may not be the *whole* truth.

How does one get to be a scientist? We propose (tongue in cheek) that many people who are destined to become scientists are people in grown-up bodies who are, in fact, still 6-year-old children. What do 6 year olds do? They ask questions. Specifically, they ask the question 'Why?' They ask 'Why' a lot! Of course, their parents patiently answer their questions, to which they again ask "Why?" To which their parents again patiently answer, to which there is yet another "Why", *ad infinitum*. Grown up 6-year-old children also like big words. When I (CF) was young, I had a friend named Jim Viets. Jim was one of the smartest kids I knew, and could say *stegosaurus* with perfect pronunciation. At that age, my lack of front teeth (and the fact that I did not know very much of anything about anything) made 'stegosaurus" uniquely difficult. These days the word might be 'transcriptional regulation' or 'gene expression', but the ability to say words that other people do not know the meaning of, or cannot pronounce, is something that came with us from age 6. When I was a kid, I used to love show-and-tell. I got to stand at the front of the class, and talk about something that only I (and perhaps my mom) really cared about. The teacher insisted that all the other kids had to be polite, and to ask me questions afterwards. That was show-and-tell. What are the posters and free communications at professional society meetings, like the American College of Sports Medicine (ACSM)? They are show-and-tell for 6-year-olds who have never quite grown up, and who still have a fondness for taking the stage and sharing what they know? Precocious 6-year-olds also like to be in charge. When I was in first grade, there was a kid in class named Richard Strickland. Richard was the 'classroom monitor'. That meant that he got to take the attendance slip from the teacher to the principal's office every day, an important task for a 1st grader. I can remember Richard walking across the classroom every day. He had the Richard Strickland walk, then he turned his head and gave the class the Richard Strickland grin, and showed the Richard Strickland attitude. He was the classroom monitor. I hated him! Later I grew up to be President of ACSM and the Editor of the *International Journal of Sports Physiology and Performance*; so I have had my Richard Strickland moments too. Wanting to be in charge is universal for 6-year-olds. When I was 6-years-old, I lived in Ft Worth, TX. Just before Christmas my parents would take me to the Montgomery Ward department store to look at toys. I could not say Montgomery Ward, so to me it was 'Monkeywards'. But, I still loved the toys. I would sit on Santa's lap and tell him what I loved the most. Today, the exhibit hall at the ACSM Annual Meeting is where I get into the mood to 'talk to Santa'. A new gas analyzer, or mass spectrophotometer, or gene splicer is essentially a "toy" to a grownup who is still a 6-year-old inside. After returning from 'Monkeywards', I would start making my 'good kid list', things I could do to make my mom and dad happy. Even though I still nominally believed in Santa Claus, I was already observant enough (a budding empiricist) to have figured out that Santa seemed to bring me more toys when my folks were really happy. What do you think grant proposals are? They are 'good kid' lists for grown up Professors? If the American Heart Association will only give me a lot of money, I can rehabilitate people from heart attacks faster than ever before! When I was 6 years old, the teacher would give out gold stars for particularly good work. I was a smart kid, and got gold stars almost every day. I would occasionally even get blue or red stars, which were for especially good work. However, I never got a 'green star'. Those were reserved for the super bright kids, like Jim Viets and Richard Strickland. What are the awards that professional societies give? They are gold, blue, red and even green stars for grown up 6-year-olds? So, science, for all its elegance, and much of its pretensions, is basically something that is done by overgrown 6-year-old kids, who kept asking "Why?". However, instead of relying on mom and dad, and a couple of favorite aunts and uncles, for the answers, the kids who grew up to be scientists developed skills to find out for themselves. Science is about human curiosity! The best scientists are curious people, always wondering why something happens, or if there is a better way of explaining what has happened. The best scientists are those who ask the most clever questions, who find the most elegant (not necessarily the most technically sophisticated) way to answer questions.

Similarly, as teachers, we are constantly reminding ourselves (and each other) that fostering this kind of 6-year-old's curiosity is much more important than conveying facts. If we foster curiosity in our students, and encourage them to go find answers for themselves, then we will be remembered as great Professors. If we allow curiosity to die, or even worse, if we kill it, then we should not be remembered at all. Instructively, the TED Talk winner from 2013, Sugata Mitra, "Building a School in the Cloud" suggests that our educational system may have become outmoded. Considering the easy access to information 'in the cloud', perhaps our goal as teachers (rather than conveying information) is to pose questions for which our students have to go find answers.

The dark side

The pursuit of Truth is not always entirely noble. Far too often throughout history, scientific questioning has resulted in the infliction of pain, injury and other forms of abuse on humans and animals. For example, grounded in the perverted sense of Social Darwinism, that overlaid the entire European colonial period of history (Haas, 2008) scientific problems were often addressed with a remarkable lack of respect for the fundamental rights of humans. For example, the practical problem of how long humans could survive in cold water was important to the military staff of the Third Reich in WW II. German pilots had their planes damaged in the Battle of Britain, and had to bail out over the North Sea. The risk-benefit of sending out rescue teams, who might themselves be attacked by the British, depended on how long the pilots could survive in the cold water. That is a simple, practical problem that depends on basic human physiology, uniform design and nutritional status. But, sacrificing inmates of the concentration camps that the Nazi regime maintained, and who most certainly did not volunteer to be immersed in cold water until they died, represents a prime example of how NOT to seek the Truth. Similarly, the Nazi regime intentionally wounded concentration camp inmates so they could learn how to treat battlefield infections in the pre-antibiotic era (e.g. a search for Truth gone awry). In the post-WW II world, experiments with athletic doping in the Russia dominated East Germany and other East Block countries was carried out with scientific precision and careful analysis. However, beyond violating the concept of 'fair play', the process of using pubertal age children, with no informed consent, without the ability to refuse to participate, and with no possibility of directly benefiting, is another example of the wrong way to search for the Truth.

Lest we create the concept that such abuses of the search for Truth are uniquely products of Nazi or Communist political systems, one has only to look at egregious examples of human subjects abuses in the U.S. The Tuskegee study, in which poor black share croppers were intentionally NOT treated for syphilis (even after appropriate antibiotic therapies were available), represents the single most well-known American example of science looking for Truth in the wrong way. Similar examples of the testing of radiation effects on soldiers, of tests of aerosol effects of infectious diseases, of intentionally giving diseases to prisoners, the elderly or the intellectually challenged are numerous enough and well-documented enough to demonstrate that the pursuit of Truth, even with a well-done experimental design, can easily go in the wrong direction, regardless of the political ideology.

In the fitness industry, the frequent claims of extraordinary effects by new pieces of equipment (the improvement is always 'up to' some magical percentage) raise serious concerns about the motivation of the search for Truth. Some of these product claims are supposedly supported by *scientific* data, although in many cases the 'science' is funded by the company making the new device. Further, the very concept of 'evidence-based medicine' is to some degree based on studies funded by the pharmaceutical industry. Although such trials are, indeed, independently overseen by national agencies like Food and Drug Administration, and have complex oversight and reporting protocols in place, it is inevitable that there is concern that the data are 'driven' by big pharma that is funding the studies. Given the relative paucity of funding from non-commercial sources for clinical trials, leading to the reliance on pharma as the sponsor of drug trials is a challenge to the otherwise very good idea of evidence-based medicine.

Even in less commercial, academic settings the career value of publishing has lured more than a few investigators into publishing weak, poorly controlled, or even overtly fraudulent data. The trend of more and more 'retractions' of articles that have survived the peer-review process and achieved journal publication has increased alarmingly over the last decade (http://retractionwatch.com). This pattern suggests that the pressure to publish is so large that the quest for Truth has been seriously confounded by the need for promotion, tenure and funding. Further, the inherently conservative nature of the peer-review process means that journals are handicapped by the tendency for reviewers (and journal Editors) to be unreasonably bound by the existing paradigm (dominant school of thought), which means that fundamentally new ideas are often hard to get published. Lastly, the reality for most scientists is that most journals have considerable page charges required for publication. Even the very good 'open access' concept was quickly corrupted by high submission fees, which created the risk of a 'pay to publish' situation and the stark reality of 'predatory' open access journals. These predatory journals send advertisements to faculty e-mails daily, encouraging submission of data that will never be reviewed adequately, by an editorial board that does not really exist, but will be published, if the open access fee is paid! These developments make it very hard for young investigators, or investigators from small institutions with limited funding (who often create the really groundbreaking scientific concepts) to publish. As an example, consider the year 1905. A young theoretical physicist, who could not even get a normal university teaching position, published three papers that revolutionized the world of physics, setting out the concept of the photoelectric effect (worthy of the Nobel prize), special relativity and Brownian motion. Had Albert Einstein been obliged to pay substantial page charges or submission fees, these papers might have remained on his desk. The history of science would certainly have been different. Thus, while publication following the peer-review process is the one of the absolute pillars of the scientific process, and a guardian of the pursuit of Truth, the economic realities of the early 21st century are forcing scientists into a position where the pursuit of Truth depends as much on funding as on their ability to ask and answer important questions.

Conclusion

Science is a process that seeks the Truth. Using a special set of rules, called the *Scientific Method*, scientists search for the Truth. Thanks to the overlapping character of scientific inquiry, from basic to translational to applied science to clinical application, the scientific process leads from a simple answer to questions about how the world works to the technological, sociological and organizational developments that drive society. Science is tough on itself. It is constantly self-correcting. Sometimes this makes for confusion, consider for example how recommendations about nutrition and exercise have changed over the last century. But it has to be that way if progress is to be made. Science is also very tough on those with something to hide in the name of retaining political, economic or even religious power. History shows that in the wrong hands, when performed without respect for human life and without integrity, science can do harm that outweighs the value of the Truth it reveals. False claims and useless ideas have been sold or perpetuated by the clever use of the term *scientific*, without following the underlying rules of science. The contemporary concerns about genetically engineered organisms, nanotechnology, artificial intelligence, the cloning of biological species (even humans) and the potential marriage of humans and technology into cybergenic organisms were anticipated by the 18th century philosopher Giambattista Vico: "If it is possible to do it, we shall do it". This contemporary '*experimentum humanum*" at some level challenges the very concept of mankind. Finally, the scientific processes itself can be co-opted and contrived into 'the business of science", which looks like science from the outside, but profits from deception and elimination of the rigor that real science deserves and demands. For all of us who started as curious 6-year-olds, and are still saying 'segasaurous' every day in our hearts, that cannot stand.

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