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## **The Role of Scientific Terminology and Metaphors in Management Education**

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### **Abstract**

Interdisciplinary studies can create synergy across various fields, allowing for knowledge in a previously specialized area to support other disciplines. A number of scientific theories and laws have been applied in other domains to explain the latter's phenomenon; the adaptation of Newton's Gravitational Law for studies of bilateral trade, diplomatic ties, migration and interaction, or the extension of Chaos Theory to biological evolution, engineering, and organizational management. Recent literature in management studies have also used scientific theories as metaphors to describe management functions and managerial behaviours. Similarly, one can apply Moore's Law to understand the exponential world. Changes are no longer linear and predictable, and the past is no longer a proxy for the future. This paper suggests that the renowned and established theories of General Relativity, Quantum Physics, the Newtonian Paradigm, Theory of Chaos, and the Standard Model have the potential to operate as extensions or metaphors to explain some aspects of strategic management. These scientific theories, and the implications of their respective terminologies, can therefore help firms better appreciate strategies and organizational designs that combat

complexities of business environments, especially those in international markets. Their use will also help managers with a background in science understand various phenomena with augmented interest and clarity, thereby improving the learning experience and depth of understanding for both professionals and management students alike.

**Keywords:** scientific metaphors, enhancing learning, globalization, education, organizational management education, interdisciplinary

## Introduction

“For newer disciplines, there appears to be a pattern of development that is based on the usage of concepts, definitions, theories, rules and principles from other disciplines. In other words, scholars determine that there is no reason to reinvent the wheel and therefore, search out those things which can or might apply to their respective area of study.” (Stock, 1997, p. 215) Scientific inquiry is one of the oldest disciplines intriguing the human mind. Since early civilisations, humans have engaged in the discovery of the nature and development of principles and laws that govern this universe. Early attempts to understand the universe were restricted to limited observation and inadequate experimentation. The scientific development that we see today is a process that began long ago, although recent centuries have shown a major expansion of scientific disciplines leading to technological advancement and innovation. Scientific knowledge and discoveries in early civilisations were rarely well recorded, transferred to subsequent generations, or shared with other scientists around the world. However, the emergence of means to share information both further and faster (such as Digital and Information Technology) has led to growth of sciences, and also ignited the emergence of many cross-disciplinary fields. In this respect, science has also influenced many other disciplines, especially management – that finds itself at the confluence of natural and social science.

There are many examples of principles of scientific theories being applied in management both as parallel concepts and as illustrative metaphors. When Gleick (1987) observed that twentieth-century science will be remembered for relativity, quantum mechanics, and chaos, he did not foresee that the implications of quantum theory and chaos would also be recognized in fields of management. No one would have also thought that principles of Newtonian paradigms can effectively explain total quality management (Dooley et al., 1995). All such works have compared the similarities between respective scientific concepts and management theories, or employed them as analogies and metaphors to explain social systems and management problems.

Though metaphorical use of scientific theories carries great potential to explain concepts and issues in management, its use is still scarce at best. The principal objective of this paper is to highlight how scientific analogies and metaphors can be

used to elaborate management concepts. Attempts have also been made to propose additional analogies and metaphors to explain the phenomenon of internationalization of businesses.

### **Using Scientific Metaphors in Management**

Metaphor is the art of comparing different things to arrive at a new understanding (Hudson, 2005). Hamilton (2000) also observes that metaphors can be used to both influence and persuade. However, she also warned that use of metaphors may also constrain and limit understanding, then used the example of the atom and the solar system to explain how powerful metaphors can be in creating new images and new meanings, and explain complex systems. Kaplan (1964) suggests that the use of analogies and metaphors to point out the awareness of resemblances serves 'the purposes of science'.

Both scientists and non-scientists have come to understand and explain themselves and their world through comparative thinking, often with the use of metaphors. For example, Stephen Hawking, in "A Brief History of Time", used the metaphor of a ping-pong ball bouncing on a table to explain the concept of relativity. Similarly, many other scientists and philosophers have used metaphors in which complex topics from areas as diverse as quantum mechanics, genetics and chemical interactions are better explained using comparisons to more mundane topics that are more likely to have been experienced by the audience, and will therefore feel more "real" to them (Hudson, 2005). In other words, metaphors are greatly helpful to explain a complex phenomenon in a relatively simple way that is understandable to the audience.

Metaphors are not only used to explain scientific theories; additionally, there are instances in which scientific metaphors have been used in social sciences or management and organizational studies. For example, *Images of Organization*, a popular work by Gareth Morgan (1986) is a reminder of how metaphors can be used in a powerful way to elaborate organizational issues and theories. Organizational scientists have also used metaphors to explain the types of organizations and describe various processes that constitute organizational activities. Morgan (1986) compared organizations with machines, brains, cultures, political systems, psychic prisons, flux and transformation, and instruments of domination. Others note that organizations may be perceived as tribes, goal-seeking organisms, homeostatic systems, and elephants (Czarniawska-Joerges, 1992).

Despite the power of scientific metaphors, their use in explaining management problems has been limited. It is only recently that metaphors borrowed from basic scientific theories have been used to describe or illustrate management phenomena. One such example is Dooley *et. al.*'s (1995) elaboration of the connections between the Newtonian paradigm and scientific management; in particular the elaboration on connections between chaos, learning organizations and total quality management. Overman (1996) has detailed performance appraisal and budgeting issues using the

metaphors of chaos and quantum theory, and argues that sciences such as physics, biology, and psychology spur us to rethink and reformulate a new “science of administration” for the twenty-first century. It should be noted that describing a management phenomenon through categorization or metaphors does not necessarily constitute the formulation of a novel theory; rather, it is a powerful tool of description (Schmenner and Swink, 1998) with which the audience can relate and easily remember.

While use of metaphors can be helpful to explain complex ideas, and a new metaphor can extend the horizons of understanding of a theoretical concept, Hamilton (2000) warns that a slavish and blind adherence to only one perspective can result in an erroneous understanding of the concept, especially if theorists do not pay attention to pertinent aspects of the metaphor. Therefore, one must be meticulous while offering a scientific metaphor in any explanation. As such, in order to discuss the use of such metaphors in the following examples in this paper, brief explanations of the concepts are necessary.

### **Background: General Relativity and Quantum Physics**

In the *Principia*, Newton suggested that the laws of motion follow the rules of 1) inertia, 2) acceleration, and 3) action and reaction. With these three laws, Newton was able to explain the motion of objects. At the time, these were considered to be infallible foundations of physics until another iconic physicist, Albert Einstein, rewrote the laws of gravitational physics. Einstein determined that Newton’s laws of motions merely projected a relativistic reality, even though Newtonian physics still provided an accurate approximation in most circumstances – with the exception of extreme speed and gravity. Instead, space and time are not independent or absolute.

The emblematic works of Einstein were undoubtedly that of General Relativity and Quantum Physics. The Theory of General Relativity connected the law of gravitation and its relations to the other forces of nature. It suggests that a planet deforms the time-space continuum, which is the background fabric of the universe (Rooney, 2006). Quantum mechanics suggests that there is an unavoidable element of unpredictability or randomness (Greene, 2004), such that even the position of a particle cannot be definite - it can only be given as a probability. Einstein was convinced, however, that “God does not play dice”, and attempted to merge the theories of General Relativity and Quantum Physics into a Unified Theory (Rooney, 2006). Purportedly, combining quantum mechanics with general relativity would confirm and validate the hypothesis of space and time as a finite, four-dimensional space without singularities and boundaries (Hawking, 2005).

Although scientists are divided on whether The Super-Unification Theory is possible, General Relativity and Quantum Physics have been useful to explain other physical phenomena like the Big Bang, cosmic inflation and black holes. The Big Bang was a result of the gigantic explosion at Point Zero whereby an infinite amount of energy

was concentrated in an infinitely tiny space. The out-burst of energy and matter was coined as the “cosmic inflation”. These matters lose energy and heat as the universe they create further expands. A black hole occurs when gravitational force overwhelms the energy received from the star’s own combustion and the gravitational force pulls the star into itself.

Yet, the idea of a unified theory stems further back into history; Plato thought that everything in this universe is of an intelligent design, as he was an avid patron of geometry and believed everything follows a pattern. This physical phenomenon finds similarities in businesses and management; just as the universe is thought to have formed and evolved, a firm establishes itself, then internationalizes or diversifies (when it becomes more successful or when in need to search for new markets to sustain its growth), and then finally relocate, exit or collapse in the market (mostly when the net costs outweighs net benefits). Likewise, there is depletion of resources or access to resources as firms internationalize into farther markets.

### **The Standard Model: A Comparison between Physics and Organisational Design**

*The Physics* (Greek: Φυσική ἀκρόασις, *Phusike akroasis*) by Aristotle postulates that everything consists of matter and form, and seeks to explain any change. The universe is governed throughout by the same physical laws and constants. The Theories of General Relativity and Quantum Physics led scientists to emerge with the Standard Model through attempts to explain The Theory of Everything; the Standard Model suggests that all matter is made up elementary particles of leptons and quarks, and that these interact via three fundamental interactions: the electroweak interaction of electromagnetism and the weak nuclear force, the quantum chromodynamic interaction of strong nuclear forces, and general relativity’s description of gravity.

The organizational design of an organization bears strong resemblance to the Standard Model. As much as matter is held together by the three forces described above, an organisation can also be described as being held together by its structure, systems, people, and values (see Table 1). The Standard Model’s interactions have different mediators, relative strengths, long-distance behavior and range, not too dissimilar to the organizational model’s interaction of structure, systems, people and values, which exhibit different levels of influences, long distance impact behavior and reach of influences.

**Table 1: Conceptual model of fundamental interactions**

Interaction	Current theory	Mediators	Relative strength	Long-distance behavior	Range
Strong	Quantum chromodynamics	Gluons	Extremely strong	Negligible	Extremely short

Electromagnetic	Quantum electrodynamics	Photons	Extremely strong	Significant	Infinite
Weak	Electroweak theory	W and Z bosons	Extremely strong	Negligible	Extremely short
Gravitation	General relativity	Gravitons	Weak	Significant	Infinite

Chandler (1962) defined *strategy* as the determination of long term goals and objectives, and the adoption of courses of action and the allocation of resources necessary for attaining these goals; while *structure* is the design of the organization through which the enterprise is administered with the lines of authority and communication between the different administrative offices and the officers, information and data that flow through these lines of communication and authority. Strategy and organizational design are inextricably intertwined (Porter, 1980; Hamel and Prahalad, 1994). Strategy and organizational structure are strongly related because an “optimal strategy” maximizes the organization’s payoff, and the organization structure implementing that optimal strategy minimizes the cost of information processing (Li, 1995). In the same way that scientists require knowledge of Particle Physics, managers must have the ability to discern themselves with the appropriate and complementing organizational design and strategies.

### Newtonian Paradigm and Management

Dooley et al. (1995) argues that the Newtonian paradigm used reductionism to form mathematical models of reality - reductionism suggests that systems are composed of independent elements, referred to as the basic building blocks. Consequently, to understand the system, one needs to completely break it down to its smallest elements and describing how these elements interact (Ackoff, 1987). Newtonian reductionism has also helped to explain other systems dealing with laws, equilibrium, or natural order - including moral, social, and political order. Prigogine and Stengers (1984) also argued that Newtonian paradigm has become a basic recipe for how new knowledge was obtained.

However, with the advent of the quantum, complexity, and relativity theories, scientific perspectives have transformed, along with the concepts of Newtonian paradigm used in management science. Dooley *et al.* (1995) drew parallels across the total quality management and chaos, and Newtonian paradigm, and argued that the tools of Newtonian paradigm are powerful and will continue to be effective for improving the quality of work-level processes. These examples show that many problem-solving tools and the spread of normative practices are indicative of the Newtonian paradigm; indicating that the Newtonian paradigm possesses powerful ability to explain management problems and offer viable solutions to these problems.

Yet, these theories and understandings will further evolve with development, akin to their physical counterparts.

### **Chaos Theory and Management**

While the concepts of chaos and self-organization have evolved from the physical sciences, the notion of complex adaptive systems has its roots in the biological sciences (Dooley et al., 1995). Gleick (1987) discovered deep and complex patterns in seemingly random or “chaotic” systems. This concept of chaos has been successfully used as a metaphor in several works on management. For example, “chaord” is a concept that is derived from both chaos and order. “Chaord” refers to “any autocatalytic, self-regulating, adaptive, nonlinear, complex organism, organization, or system, whether physical, biological or social, the behavior of which harmoniously exhibits characteristics of both order and chaos” (Chaordic Commons, 2004). The term ‘chaordic’ then refers to anything that is simultaneously orderly and chaotic, existing in the phase between order and chaos (Chaordic Commons, 2004).

Based on Wilber (1996), Fitzgerald (1996) articulates five core characteristics of chaordic systems. These are illustrated as follows:

Consciousness (thinking, as opposed to doing, is the prime engine of a chaordic system);

Connectivity (the chaordic system is one unbroken and unbreakable unity);

Indeterminacy (the chaordic system is so dynamically complex and highly sensitive to initial conditions that any link between cause and effect is necessarily obscured, rendering its future indeterminate);

Dissipation (the chaordic system is a dissipative structure, perpetually cycling through a process of ‘falling apart’ and ‘back together again’ in a novel new form ungoverned by the past); and

Emergence (the inexorable thrust of the chaordic system is toward infinitely ascending levels of coherence and complexity).

These five properties illustrate that human initiative is central in chaotic system thinking (Eijnatten *et al.*, 2007) - therefore, processes such as dialogue, multilogue, and emergent leadership are critically important mechanisms.

Given the complexity of today’s organizations (Boal and Schultz, 2007), which are intricately intertwined with individual and social demands, constraints, and choices (Stewart, 1982), leadership in organizations is even more complex and adaptive (Marion and Uhl-Bien, 2001). Under such systems, its primary task is to establish a dynamic system where bottom-up structuration emerges and moves the system (and its components) to a more desirable level of fitness and order (Osborn and Hunt, 2007). Such a leadership capacity required to reach toward the desired order is more intricate and complex, and is most likely shared among managerial leadership role

holders instead of being concentrated in a single individual, especially in complex adaptive systems. In executive level leadership positions, leaders face more external pressures and less internal constraints while they develop, focus, and enable an organization's structural, human, and social capital and capabilities to meet real-time opportunities and threats (Boal, 2004). They engage in sense-making of environmental turbulence and ambiguity, and sense-giving to their followers. They regularly operate on the edge of chaos and perform what can be termed as "chaordic leadership".

This view of management through the lens of complexity and chaos is increasingly emerging in project management studies as well. Thomas and Mengel (2008) argue that projects and project environments are recognized as being influenced by complexity, chaos, and uncertainty, necessitating improved project management education and development of project managers. Project challenges seem to be increasing (Toor and Ofori, 2008) and projects are being managed on the edge of chaos. The diverse range of challenges faced by organizations and projects requires leaders to respond to each situation on its individual merits (Raiden and Dainty, 2006). It therefore calls for leadership that fosters continuous change, creative and critical reflection, self-organized networking, virtual and cross-cultural communication, coping with uncertainty and various frames of reference, increasing self-knowledge and the ability to build and contribute to high-performance teams (Thomas and Mengel, 2008). One such project management technique is aptly named "Agile Project Management", to reflect the necessary traits of such leadership in a constantly dynamic situation – another example of metaphors that accurately represent reality, and serve to form the necessary mindsets. (Canthy, 2015)

In other works, Dooley *et al.* (1995) draw more parallels across total quality management and chaos. They present the notion that control is equated with the Newtonian paradigm whereas organizational learning - which involves creativity and innovation - is equated with the complexity paradigm. Dooley *et al.* (1995) argue that, in order to achieve total quality management in an organization, "one must manage systems to be in control and out of control (i.e. learning by experimentation) at the same time" (p. 17). They also note that elements of total quality management – such as organizational, planning, and strategic elements – are indicative of a complexity paradigm. Similarly, Overman (1996) argues that use of the chaos theory parallelism enhances our understanding of administrative behaviors and fosters the idea that real change and innovation can be achieved through chaos instead of preventing it through control. Overman (1996) also observes that management problems such as performance appraisal and budgeting can be successfully addressed through the concept of chaos.

These examples show that there are fairly strong links across the concepts of chaos (e.g. self-organization, dissipative structures, and dynamic complexity) and management. However, given that the work on chaordic organizations and complex

adaptive systems is still emerging, there is a lot more yet to be known in this area. Studies using the chaordic model have been found in use in hotel management (Pappas *et al.*, 2019) and comparisons between different types of social ventures (Miller-Stevens *et al.*, 2018) – these studies imply that the model is indeed a valid parallelism and provides an explanation.

### **Quantum Theory and Management**

According to Shelton and Darling (2001), the current era of technological development can be called “The Quantum Age”. While quantum mechanics has completely transformed modern technology, it also has a lot to offer to management sciences. Overman (1996) argues that the applications of new sciences – such as quantum theory – are significant and rapidly growing in the area of management and administration. He applied the metaphors and methods of quantum theory to familiar management issues such as performance appraisal and budgeting. Overman also presents the notion of the “quantum organization” and observes that “the quantum organization will require even greater participation and collusion among actors with common purpose, and even greater reliance on nontangible and nonindividual patterns of compensation and identity” (p. 87).

Shelton and Darling (2001) argue that human beings are also quantum beings and that the metaphor of quantum theory can be successfully used to explain managerial behaviors. Using “quantum theory”, Shelton and Darling (2001) proposed the quantum skills model for leadership behaviors, echoing the interest in relating scientific theories with management concepts. The quantum skills model incorporates seven skills:

Quantum *seeing* – the ability to see intentionally;

Quantum *thinking* – the ability to think paradoxically;

Quantum *feeling* – the ability to feel vitally alive;

Quantum *knowing* – the ability to know intuitively;

Quantum *acting* – the ability to act responsibly;

Quantum *trusting* – the ability to trust life’s process; and

Quantum *being* – the ability to be in relationship.

Where quantum seeing, thinking, and feeling are psychological in nature, quantum knowing, acting, and trusting are grounded in what is termed as “spiritual principles”. Quantum being, as Shelton and Darling (2001) put it, is intricately connected to each of the other quantum skills. Its central position in the model reflects this connection. Proponents of quantum skills model believe that it is key to enhancing leadership effectiveness.

## **Quantum Mechanics and Ideation**

Henry P. Stapp, a popular physicist, offers an interesting relevance of quantum mechanics with the 21<sup>st</sup> century business world. While speaking at the Neuro Leadership Summit in Aslo, Italy, Stapp (2007) argued that quantum mechanics describes the dynamics of ideas. Since 21<sup>st</sup> century business management is primarily more driven by rapidly changing ideas than by slowly changing material factors. Stapp furthered his argument by making a reference to structures of social organizations, businesses, and industries that were a reflection of the reigning scientific conceptions of their times; in particular, Newtonian mechanics, which was based upon the idea of a point particle that was supposed to have a predefined location, velocity, and trajectory in space-time. Conversely, the modern theory of mechanics showed that the particle can be associated with the notion of continuous smear of possible locations and possible velocities.

This perspective of quantum mechanics suggests that in order to understand what was actually going on, one should interpret the continuous smear of possibilities as a potentiality for an event to occur. Stapp suggested that an event is psycho-physical in nature and has both an idea-like as well as physical aspect. In this respect, ideas are both basic realities and causal drivers. In the slow-moving age of machines Newtonian mechanics played an influential role. But in today's dynamic world and rapidly changing circumstances, continuous development and flow of ideas and their efficient deployment in business design and strategy is central. This transformation underscores the need for dynamic flow of ideas making humans both the creators and implementers of concepts. Stapp thereby used the metaphors of quantum mechanics and its laws to explain how complex problems of our world can be solved.

Overman (1996) also suggests that adoption of the metaphors and methods of quantum theory possess a great potential for management sciences in the future. Above examples of use of quantum theory to explain management problems and managerial behaviors show that quantum theory can be used as a metaphor in numerous other pertinent areas of management.

## **Principles of Physics for Management**

It is crucial that the other laws of physics are also recognized because the laws in science and physics are very much interconnected and inter-related. Insomuch that the Gravity Model has been used to observe phenomena in social sciences like bilateral trade, diplomatic ties, migration and interaction; and the extension of the Chaos Theory to comprehend biological evolution, engineering and organizational management, the paper recommends the application of other established laws of physics to the management of the internationalizing firm. Table 2 lists these laws of physics – which Baker (2008) lists in her recent book on “50 Physics Ideas You Really Need to Know” – and their respective interpretations with respect to management, showing that the laws of physics can be successfully imported as metaphors to explain

various management and administrative phenomena ranging from environmental scanning and business competitiveness to internationalization of organizations and management of chaos in foreign cities.

**Table 2: Key laws of physics (as metaphors) and their application in business and management**

Laws of physics	Business / Management Interpretation
Environmental Scanning	
Maxwell's equations described how both electric and magnetic fields are manifestations of the electromagnetic wave.	The business climate is constituted by many inter-related factors and is manifested in many ways.
Particle physicists think space is a cauldron of subatomic particles being continually created and destroyed; and mass, inertia, forces and motion may all be manifestations of a bubbling quantum soup.	Business environments are complex. Forces of influences are constantly demolished and created.
Snell's law on refractive indexes. Fraunhofer diffraction describes the blurring for light rays reaching us from a distant landscape.	Wearing different lens or taking up a different method of due diligence may give the management different interpretation of the environment. Distance may dilute understanding.
The Doppler effect has been used to measure speeding cars to motion of the stars and galaxies.	Firms can use business due diligence instruments to measure business viability and feasibility of business venture. Business intelligence gives leverage to the firm.
Standard model suggests that protons, neutrons and electrons are just the tip of the particle iceberg. There are still smaller quarks, neutrinos, photons etc.	Data gives information; information gives knowledge; and knowledge gives wisdom.
Internationalization of MNCs	
Kepler described how planets follow elliptical orbits and how distant planets orbit slower around the sun.	Foreign subsidiaries of an internationalizing organization follow the organizational make-up or traits of the local head-quarters. Influence from the head-quarters on the foreign subsidiary depends on the intervening distance between them. Distance can be expressed culturally,

	administratively, geographically, or economically (CAGE of distance).
Hooke's law of elasticity suggests that a spring extends proportionally to the pulling force exerted on it.	The performance of an overseas office may be affected by the level of control exerted, and empowerment and autonomy allowed by the head-quarters.
General relativity - light could be bent by gravitational field.	Everything is relative to one another.  The size of the firm or the size of investment, and the intervening distance between the home and host markets affects the conditions for internationalizing firms to venture into overseas markets.
<b>Chaordic Management and Organization</b>	
The Second law of thermodynamics says that heat travels from hot to cold bodies or from high entropy to low entropy, from chaos and mess to organization.	A firm seeks to organize its resources by means of company policies, organizational structure, operating systems, shared values etc.
Dark matter takes up ninety percent of the universe. Yet, it has its own mass and gravitational pull.	Unknown factors lurk around and can throw unwanted surprises to the firm.
The Chaos theory noticed that when 0.123456 was replaced by 0.123 in a weather forecast simulation, the predictions can be completely different. This led to the saying that the fluttering of a butterfly in Brazil can cause a torpedo in Texas, widely known as the "Butterfly Effect".	A small detail gone awry can spiral and balloon to become a crisis. Elaborate risk evaluation may be crucial for investments or projects.
Newton's theory of colour and his prism broke up white light into red, orange, yellow, green, blue, indigo and violet.	The management must have the astuteness to break up problems and decisions into individual components so that varied stakeholders' perceptions and interests are taken care of.
Heisenberg's uncertainty principle states that the speed or position of a particle cannot be exactly precise - indeterminism.	The world is ever-changing and dynamic. The firm must not be static either. It has to be progressive to avoid being phased out by strong competition and demanding clients. Flexible and contingency strategies are necessary to survive.

<p>The Copenhagen interpretation rules that the observer's interventions fix the outcomes of quantum experiments.</p> <p>The Schrödinger's cat suggests until the outcome was actually observed, the cat should be in a state of limbo.</p>	<p>Managers must be open-minded. This is the essence of "Blue-ocean" thinking and strategy.</p>
<p>Nuclear fission and fusion.</p>	<p>Sometimes, problems need to be broken down into their elements; sometimes, issues can be lumped together and given an integrated solution for dynamic synergy</p>
<p>According to Mach's principle, objects far away affect how things move and spin nearby. This idea of relative versus absolute motion inspired Einstein to derive his theories on general and special relativity.</p>	<p>Everything is related to everything else, but nearby objects are more related than distant ones (First law of geography). Therefore, managers will have to consider causes of things unfolding around them and implications of their decisions.</p>

### Discussion and Conclusion

Use of metaphors to explain ideas and to convey messages is prolific in the modern age. Business, advertising, and technology communications employ metaphors and analogies to elaborate complex ideas and convey simpler messages to the public. In this paper, the authors have attempted to make a case that management science can greatly benefit from the use of scientific metaphors and analogies.

Business authors have been writing on relationships between warfare and business strategies when they attempt to transpose the wisdom of Sun-Tzu, Miyamoto Musashi, and von Clausewitz to train shrewd, judicious and incisive organizational managers. This paper advocates that the laws fundamental physical sciences can also be used to impart clear understanding and knowledge of the complexities of their business endeavors (Wee, 2017).

The rate of spatial expansion is accelerating, much like the dynamics of the world. Firms have to deal with a swelling multitude of environmental factors, especially with escalating globalization and proliferation of information and infrastructural technology. An appreciation of the phenomena of science (e.g. physics) can help managers to cope with dynamics of the new-age business world, and enable them to derive suitable strategies and organizational designs to combat the wide hosts of issues that they are currently facing and will continue to face in the future. Therefore, it is necessary that more concerted efforts are made by researchers to explain the processes and complexities of management through metaphorical use of scientific laws and theories.

There are striking similarities in the evolution of the firm – from establishment, to market-entry of internationalization or diversification, then shrinkage and exit – with

the laws of physics. Could it be that there is indeed a 'Grand Intelligent Design' that unravels a prevailing law that formulates everything, including the best model for business strategies and organizational design? Perhaps the human race will continue to endeavor to discover that 'Grand and Intelligent Design' that governs the universe. However, with the existing knowledge of science, we can learn a great deal and explain many complex aspects of business through metaphors and parallelisms.

A large proportion of managers in technology-driven firms come from a technical/engineering background. These professionals have a robust knowledge base of basic science, are well aware of basic science principles, are comfortable with scientific explanations of complex phenomena, and as a result can easily relate to the scientific metaphors to help them understand various principles of modern management. Therefore, while training engineers or professionals with technical background for such roles, use of scientific metaphors can be greatly helpful. These metaphors are not only easy to understand for knowledge workers in technology-driven organizations, they are better retained in their memory and hence put to use in everyday practical life of professionals.

Use of scientific metaphors should also find its place in university courses at both undergraduate and postgraduate level. Scientific metaphors can deepen students' understanding, especially those who are pursuing multidisciplinary courses or those who wish to pursue management careers but have a science background.

Discourse between students across science and management backgrounds can also help unravel various complex management phenomena. Such metaphors can also help generate the interest in management studies among students with science backgrounds – especially since many of these students are likely to play a managerial role as some point in their careers.

Engineering students in particular have strong science fundamentals, having been exposed to various basic science theories since their secondary education as a requirement.

Therefore, it is likely that engineering students will find management courses more interesting, appealing, and understandable if they are taught and reinforced through scientific metaphors.

This approach can be particularly useful for management-related courses under programs such as Construction Management, Engineering Management, Project Management, and Facilities Management.

Christensen *et al.* (2008) reminds us that while Education can be measured in scientific terms, some of it still remains an art, that relies on the instructor's proficiency and sound judgement to "understand and relate to students".

Yet, it is also recognized that a fair amount of education research is halted at "statements of correlation but not causality".

Christensen *et al.* observes a similar trend, disturbingly so, in business research. As such, we believe that more work is needed to include additional scientific metaphors that can explain various management phenomena.

Heavy collaboration is required among the academics who are interested in this line of inquiry and industry practitioners.

Given the potential of use of scientific metaphors in academic education and professional training, such collaboration can reap many benefits – some of which were discussed earlier – in the future.

To quote Christensen in closing, “education research must move toward understanding what works from the perspective of individual students in different circumstances as opposed to what works best on average for groups of students or groups of schools”.

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