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About Science 1: Basics —Knowledge, Nature, Science and Scimat

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There is a lot of confusion and misconception concerning Science. The nature and contents of science is an unsettled problem. For example, Thales of 2,600 years ago is recognized as the “Father of Science” but the word science was introduced only in the 14th century, and so it is obvious wrong if science is understood as modern science only, which started with Galileo about 400 years ago. If science is mainly about nonliving systems, then social science cannot be part of science. And if social science is part of science, then why the humanities, which are also about humans, are not part of science? All these confusions and dilemmas concerning science could be traced to the historical evolution of the word and concept of Science and the many misconceptions perpetuated by various philosophers and historians of science, due to the lack of an agreed-upon definition of science. This chapter aims to clear up all these confusions by retracing the historical development of science—the word, concept and practice. The nature of knowledge, Nature, religion and philosophy are covered. A simple definition of science according to scimat, the new discipline that treats all human-dependent matters as part of science, is provided. Three important lessons learned about science, including the required Reality Check (which differentiates science from other forms of knowledge) are given. Important ramifications from this definition concerning antiscience and pseudoscience in particular are discussed.

1.1 Introduction

Science is one of the three pillars that support an advanced civilization, East and West. While the other two pillars, ethics/religion and arts, have an extremely long history of at least one million years [Lam, 2011] science, counting from the days of Thales (c. 624-c. 546 BC)—the Father of Science—has a “short” history of only about 2,600 years. Short as it is, it is long compared to the span of modern science, a mere 400 years or so since Galileo (1564-1642).

While the tremendous success of modern science did lead to positive results (and important applications like the cell phone), unfortunately, it also led to all sorts of confusion among the philosophers, historians, sociologists and communicators whose works are related to science; e.g., the definition of science is often avoided in philosophy of science books [Oldroyd, 1986; Godfrey-Smith, 2003]. The confusions concern three aspects of science: (1) the contents of science, (2) the existence and nature of the different stages in the development of science, and (3) the scientific research process.

The crux of the problem is that the concept and practice of science are not constants but have evolved over time, with many twists and turns, contributing to the *lack of an agreed-upon definition of science*. Thus, most statements made on science more than 56 years ago (the year 1957, see Section 1.7.1) by scholars and even by scientists turn out to be no longer valid. To clear up the confusion, the historical development of science over the last 2,600 years since Thales is retraced. And since the essence of science is to gather knowledge about Nature, the idea of Nature and the nature of knowledge are reexamined, too. It turns out that, based on our current scientific knowledge and the historical record, two simple conclusions are reached: (1) Humans are part of Nature, and (2) the aim of science was never to challenge the existence of God but merely to see how far humans can go in understanding what is around them by reasoning without appealing to God. These two recognitions, missed by many others, form the premise of s*cimat* (Science Matters), the new discipline initiated in 2007/2008.

In Section 1.2 below, two kinds of human knowledge and the “knowscape”, a metaphor for the landscape of knowledge, are introduced. The rationale behind scimat, which treats all human-related matters (covered in the humanities and social science) as part of science and the importance of the humanities are presented in Section 1.3. And since science first appeared (without the name) as part of philosophy in early Greek time, which was humans’ first attempt to break away from superstitions (if you exclude God from superstitions), the connection between religion and philosophy is examined in Section 1.4. The historical developments of the idea of Nature and of the idea of science (a very recent concept) follow (Section 1.5).

In Section 1.6, the very definition of science and of scientist according to scimat are presented, which are simple, clear and historically correct. Science Room, the metaphor for science, is also included. Section 1.7 outlines how science was actually done, for both simple (mostly inanimate) systems and complex systems (which include human and nonhuman animate systems). The contents of this Section influence heavily our discussion on the philosophy, history, sociology and communication of science, presented in [Lam, 2014]. Three important lessons learned about science are given in Section 1.8. A summary of the spirit and essence of scimat (in the format of Q & A), and the ramifications from the basics about science are given in Section 1.9. Finally, Section 1.10 concludes with discussion and a take-home message.

1.2 Human Knowledge and the Knowscape

In spite of the many different opinions, we could probably agree that "Science is to understand Nature."[1] Then what is Nature? The present understanding is: Nature consists of all material systems including humans and (living and nonliving) nonhumans. That humans are part of Nature is a relatively new recognition. It follows from Darwin's evolution theory [1859] that humans are a living system like the chimpanzees and evolved from the fishes, say. Humans are thus one of the many kinds of animals[2] and a material system and, like all material systems, are made up of atoms. Note that the existence of atoms was

[1] Some people prefer "Science is to understand the universe". But since Nature includes everything in the universe (see Sections 1.3 and 1.5.1) the two statements are equivalent to each other. Here, "understand" means to understand without appealing to supernatural or God. See Sections 1.5.2 and 1.6.1 for a historical discussion of this position, which is adopted in this chapter and in scimat.

[2] Plato seems to recognize this when he defines humans as featherless, bipedal animals with broad nails [Läertius, 2011].

established only about 100 years ago due to Einstein's work on Brownian motion [1905]. Consequently, most discussions on the contents of science published 150 years ago are simply wrong or misleading, resulting in many misconceptions.

All knowledge about Nature accumulated through science by humans could be divided into two parts: A human-independent part[3] and a human-dependent part [Lam, 2008a]. An example of the former is the law of gravity, which could be discovered by aliens, too, if they exist. The latter includes knowledge of human-made materials such as semiconductors and all the topics in social science and the humanities.[4]

To facilitate discussion in this chapter, we introduce the *knowscape*, the landscape of knowledge. It is meant as a metaphor, and, as a metaphor it is far from perfect and has its limitations, e.g., not everything in the picture should be taken literally. In the knowscape (Fig. 1.1) there are hills/mountains, valleys and plateaus all linked to each other in a vast terrain, and some man-made lakes. Each hilltop represents a highlight in human knowledge; the height of the hill corresponds to the difficulty of reaching it. And, as in real mountain climbing, the explorer usually has to pass a lower hill before reaching a higher one. A researcher (whether you call her/him a scientist or not) is the explorer.

However, there are two types of mountains. One type is human independent which is out there whether humans exist or not (and could be found by aliens, say), represented by the upper curve in Fig. 1.1. The other type is human dependent, the knowledge found in the humanities and social sciences (lower curve). The isolated lakes represent artificial, nonhuman systems (such as semiconductor, computer and artificial life) which are human dependent, too (ellipses).

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[3] The existence of human-independent knowledge is denied by some relativists. *Relativism* is a branch of philosophy started by the ancient Greeks in 5th century BC. In those times, the profession of lawyer did not exist and everyone has to argue for himself in court. The relativists played the role of legal advisors. Like in today, winning the case is the only aim of arguing, not reaching for the "truth" or "reality" [Buckingham et al, 2011, p. 42].

[4] See [Doren, 1991] for a concise review of human knowledge.

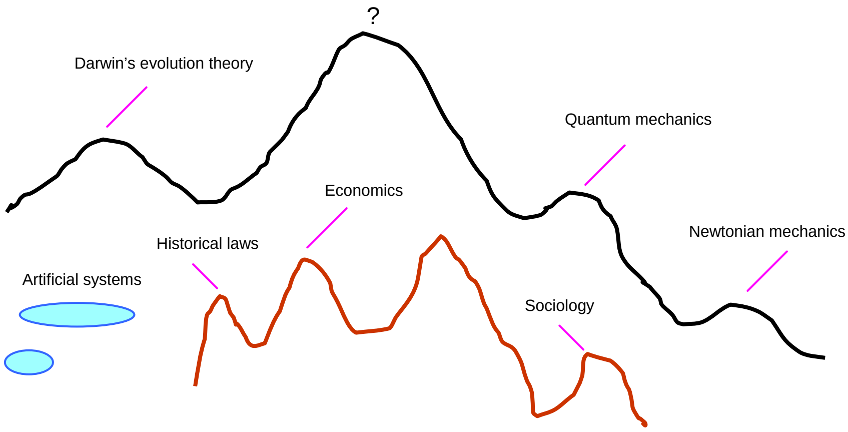

Fig. 1.1. The knowscape: Landscape of knowledge. The upper curve represents the human-independent part; lower curve, human-dependent part related to human matters; ellipse, human-dependent part related to artificial systems.

1.3 Scimat 1: The Humanities

And so we have these three recognitions.

1. Science is to understand Nature.
2. Nature includes all material systems.
3. Humans are a material system.

The logical conclusion derived from these three statements is that "all things related to humans are part of science". What are "all things"?

Let us consider bees which, like humans, are a kind of animal. When we say "all things related to bees" we mean the biological property of a single bee, the behavior of a single bee or a group of bees living together (how they communicate with each other; how they divide jobs among themselves; how their society is organized; etc.), the competition or cooperation between different groups of bees, and so on. Everything! The same goes for chimpanzees. And so, the same goes for humans.

Historically, the study of different aspects of humans was classified into medical science (including human biology), social science and the humanities. Medical science is about the biology of a single human or a group of humans; an example of the latter is epidemiology. Social science (e.g., economics and sociology) is the study of some, but not all, aspects of a group of humans. Cultural study, a branch of the humanities, is about a group of humans, too. It is thus clear that the division of social science and the humanities is not according to the number of humans under study. Rather, as pointed out before [Lam, 2008a, p. 13], it is due to the scientific level achieved in these two large group of studies. Yet, for some people, it is due to the belief that the humanities can *never* be a part of science either (1) because humans are so complex that it cannot be handled by science or (2) because humans are fundamentally different from the bees and chimpanzees. These issues form the core of this chapter and will be clarified later. At this point, let us note that this classification of human studies was established well before the times of Darwin and Einstein, and the separation of the humanities from science has been maintained, for many people, even today. As shown below, it is due mostly to the misconceptions about science.

Why is it crucial to recognize the humanities, as it should, as part of science? The answer lies in the importance of the humanities. This point could never be overstated even though it is usually overlooked in every country, perhaps with the exception of France where philosophy is a required examination for graduating high school students since the Napoleon days. Humanities' importance could be seen from these two considerations.

1. If all the present "science"[5] research projects were frozen or eliminated, the world would still be the same—chaos and tragedies would continue—because it is the humanities which include decision making, underdeveloped in the last 2,600 years since Plato (427-347 BC), that matter in human affairs.[6]

[5] In this chapter "science" with double-quotation marks means science in the conventional sense, which is the sum of natural science and social science but excludes the humanities (see Fig. 1.2).

[6] For example, according to Jean Ziegler [2013], the hunger and malnutrition suffered by nearly one billion people in the world results not from failure of agriculture, science or technology but from inhumane and shortsighted politics.

2. Apple company is successful because they put a humanist, Steven Jobs (1955-2011), in charge of the engineers—good for the economy.

Further discussion on the humanities is given in Section 1.10.

Scimat is the discipline initiated by Lam [2008a; 2008b] that treats all human-dependent matters, humanities in particular, as part of science. (See Sections 1.6 and 1.9 for more discussion of scimat.) The Scimat Program[7] is the latest concerted (international) effort in reviving the Aristotle tradition of treating human and nonhuman systems alike in the pursuit of knowledge. (See Fig. 1.3 and Section 1.10 for a discussion of the past efforts that failed.)

That such a simple and almost trivial conclusion that the humanities are part of science is not immediately and universally accepted by every learned person is at first puzzling. It turns out that the reasons lie in people's understanding of what science is and what the word science represents to them. A little bit of research shows that (1) not just laypersons but even some good "scientists" hold the wrong ideas about science, (2) the root of the problem is mostly historical, and (3) misconceptions about science could be traced to the inadequacies in the four disciplines concerning science, viz., the philosophy, history, sociology and communication of science. Below the historical root of the problem is discussed; each of these four disciplines is examined in the next chapter [Lam, 2014].

1.4 Religion and Philosophy

The chimp and human lineages split from each other six million years ago. Four million years later *Homo erectus* appeared and already possessed the ability of mimesis [Donald, 2006]. Then, 1.6 million year ago, fire and complex stone tools were invented. It is thus not hard to imagine that about a million years ago, our ancestors though primitive were sophisticated enough to think and wonder about things they saw

[7] The Scimat Program was started by Maria Burguete and Lui Lam in 2007 with the first international scimat conference in Portugal and the forming of the International Science Matters Committee. For more see: www.sjsu.edu/people/lui.lam/scimat.

and the happenings in their lives. They might ask: Why does the sun rises and disappears everyday? Why am I sick and recovered but not the one next to me? They might even ask: Who am I? This was likely to happen because, apart from hunting and mating, there was plenty of leisure time; there were no televisions or football games to watch [Lam, 2011]. Besides, curiosity helped in survival [Lam, 2004, p. 36].

We do not know what answers they came up with since there was no record to show; writing had not been invented yet. But we do know what answers their descendents, *Homo sapiens* who appeared in the scene 195,000 years ago, came up with. More precisely, we mean the later generations; their answer: Everything is due to “something out there”, the supernatural.

This is understandable. In the absence of scientific knowledge at that time, it is natural to explain everything by using analogies and lessons learned in their daily lives. Consequently, the ascent and descent of the sun or the moon is governed by a human-like god, like the way a piece of rock could be moved by a human being. When one is sick, without the benefit of any medical knowledge, an easy explanation is that a certain god was offended. To get well again, the god’s anger had to be removed, and that could be done by bribery—in the form of animal or human sacrifices—in the same way that it works with humans themselves.

What we call superstition was refined by the ancient Greeks in the form of mythology, with numerous gods with specific names. For example, Apollo takes care of the Sun while multitasking in light, knowledge, music, healing and the arts; Boreas, the north wind; Notus, the south wind; Zephyrus, the west wind; Apheliotes, the east wind. Similarly, human matters are governed by gods; e.g., Eros the god for love and sexual intercourse; Athena the goddess for intelligence, skill and wisdom [Buxton, 2004]. Two points about this “theory” of gods: (1) It is consistent with everything they know at that time.[8] (2) It treats human and nonhuman systems alike, by the same mechanism.

[8] In fact, even today’s science has not proved that Apollo (or any of the Greek Gods) does not exist. We just do not need them or believe in them anymore because we have a simpler and better answer in explaining why the sun rises in the East and sets in the West.

This romantic theory of gods is clumsy and suffers from the lack of evidence and predictive power, even though predictive power is not the necessary quality of a new theory. In fact, the gods hypothesis is already being criticized in the 6th century BC by what is later called philosophers[9] who prefer to explain natural phenomena in terms of natural causes. Thales is the most important and famous one who claims the nature of things is water and is said to have predicted the eclipse of the sun happening in 585 BC [Cornford, 2004, p. 1]. But he also maintains that the universe is alive with soul in it, full of daemons or gods [Cornford, 2004, p. 127; Lloyd, 1970, p. 9]. Aristotle (384-322 BC) suggests that the inquiry into the causes of things begins with Thales [Lloyd, 1970, p. 1] who is the first to define general principles and set forth hypotheses, and has thus been dubbed the "Father of Science".[10] (The word science first appears in the 14th century; see Fig. 1.2.)

Meanwhile, the number of gods is reduced from many to one [Armstrong, 1993], reflecting humans' desire for simplicity. This principle of simplicity remains in the core of modern science and is called Occam's Razor: What can be done with fewer is done in vain with more, i.e., the simpler the better (as long as the simpler works). With one God, organized religion as we know it today emerges.

Philosophy, starting with Thales, is the effort to understand and explain things in the universe—the nonhuman systems and even the human system[11]—through reasoning without bringing in the supernatural or the gods/heroes. It has two parts: one part that God is not brought in explicitly and another part that God is purposively and explicitly put there [Buckingham et al, 2011]. Thales' water hypothesis is an example of the former; Aristotle's "unmoved movers" in *Metaphysics*, the latter

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[9] The two words philosophy (meaning "love of wisdom") and philosopher are coined by Pythagoras (c. 570-c. 495 BC) [Bertman, 2010, p. 244]. The word 'philosophy' with the meaning of "all learning exclusive of technological concepts and practical arts", enters the English language in the 13th century [see: *Webster Ninth New Collegiate Dictionary* (Merriam-Webster, Springfield, MA, 1984)]. Unless otherwise specified, all the dates of words appearing in the rest of this chapter are from this Webster dictionary.

[10] en.wikipedia.org/wiki/Thales (July 27, 2013).

[11] The assertion of the historian Robin Collingwood (1889-1943) in *The Idea of Nature* [(1945) 1960, p. 3] that philosophy is exclusively concerned with the physical universe is wrong.

[Collingwood, 1960, p. 87]. It is the former (but not the latter) that is identified as science in modern time.

Philosophy is a transition from the "narrative" or "story telling" to "reasoning"—a big step forward. Note that what the ancient Greeks abandon are the primitive supernatural and the relatively simple gods/heroes; they do keep the more sophisticated God, which actually is a central part of their knowledge system. In fact, philosophy *never* challenges the existence of God; it just assumes *a priorily* that part of the universe could be understood through reasoning (which turns out to be correct as shown by later developments). That this is at all possible is quite trivial since no one knows how God runs the universe after he creates it. For example, God could lay down the rules or laws and go fishing and comes back occasionally to burn down a city if he finds a sizable portion of the residents' attitudes are God-incorrect, or he could be a CEO who manages minutely every happening, big or small. In either case, philosophers, if they so wish could easily claim that what they do is just reading the mind of God. And this explains why, e.g., Plato, Aristotle and Immanuel Kant (1724-1804) could do their philosophy while still believing in God.

Since philosophy comes after religion which includes mystic considerations, there exist in philosophy two lines of abstract speculations among pre-Socratic thinkers, leading to two traditions: scientific and mystical. The scientific trend puts the gods completely away in reasoning, reduce the Soul to material particles, and concentrate in inanimate systems, more in line with modern science. It starts with the Milesian school (Thales, Anaximander and Anaximenes) and leads to Democritus (c. 460-c. 370 BC) who proposes that everything is made of atoms. The mystical trend is "rooted in certain beliefs about the nature of the divine and the destiny of the human soul" and tries "to justify faith to reason." It is exemplified by Pythagoras and Plato [Cornford, 2004]. The two traditions coexist and influence the development of philosophy for a long, long time, and are still among us today.

1.5 Nature and Science

Both the concepts of Nature and of science evolved with time which, when ignored, resulted in many misconceptions and a lot of confusion among the scholars on science.

1.5.1 *The Idea of Nature*

The word "nature" has two meanings, same in ancient Greek time and modern time: (1) the sum total of natural things; (2) the principle (or source) governing natural things. It is mainly the first meaning, the contents of Nature, which concerns us here. In particular, (1) Do the natural things include humans? (2) If so, do humans differ from other animals? (3) And if so, could the distinctions be explained completely on a material basis?

First issue first. In the 6th and 5th centuries BC, philosophers of the Ionian school (of which the Milesian school is a subset) believe that (1) there is such a thing as "nature"; (2) nature is "one"; (3) the thing which in its relation to behavior is called nature is itself a substance or matter [Collingwood, (1945) 1960, p. 46].

For Aristotle of the 4th century BC, nature is the essence of things which have a source of movement in them [p. 81], which, therefore, should include humans. It is in later years that humans are excluded from the domain of natural things. This issue is settled with Darwin's discovery [1859] that humans, like other animals, evolve from other more primitive creatures and organisms; *humans are thus part of Nature*.[12]

The second issue of whether humans are distinct from other animals has two levels. At the first level, we all know that through adaptation and

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[12] Of course, it took many years before Darwin's evolution theory was accepted by the mainstream, which, in fact, is still rejected by many laypersons on religious grounds. It is thus worthwhile to point out that in 1996, Pope John Paul II has declared that Darwin's evolution theory is indeed correct and covers humans, too, except that a human being, unlike other animals, is infused a soul by God when it becomes into being [Pope, 1996]. And this was four years after the same Pope admitted that Galileo was mistreated by the Vatican and apologized (www.vaticanobservatory.org/index.php/en/history-of-astronomy /197-the-galileo-affair, Nov. 29, 2013; New York Times, Nov. 1, 1992).

heredity humans have evolved to be quite distinct from other animals; e.g., our brains are larger; we have invented written language; etc.[13] [Suddendorf, 2013; Pollard, 2009]. The second level is more sophisticated: the existence of "soul", consciousness, and free will that are thought to be uniquely human. This is fine. We all have a vague idea of what these are since we could experience it ourselves.

The third issue of where do soul and free will come from has been investigated intensively by philosophers, past and present, and more recently, by neurobiologists. The majority opinion currently is that they are emergent phenomena/features derived from the neurons and their connections [Gazzaniga, 2012; Tse, 2013]. In other words, the mind-body problem will be solved by neuroscience; it also means that it is not yet a settled issue.

1.5.2 *The Idea of Science*

The word science first came into English in the 14th century and its present usage appeared even later, in 1867, soon after the Age of Revolution (1775-1848, such as the Industrial Revolution and the French Revolution). Science comes from Latin *scientia*, meaning "knowledge" or "the pursuit of knowledge", and especially "established theories" when it first appears [Williams, 1983; Ferris, 2010, p. 3].

Since Thales is called the Father of Science, naturally, science (no matter what it means) should already exist in 600 BC. What was it called then? It was called philosophy; more precisely, it is that part of philosophy that God is not mentioned explicitly (see Section 1.4).[14] For example, Aristotle's works on biology are science; his works on the human system such as ethics and arts, in our opinion, are also science (at the empirical level; see Section 1.7.1). Another example: the works of Archimedes (c. 287-c. 212 BC) on buoyancy, the Archimedes' Principle, is obviously science, even by the present definition of the word.

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[13] On the other hand, there are more similarities between humans and other animals than we are ready to admit [Natterson-Horowitz & Bowers, 2013].

[14] Collingwood has remarked: What we call science, Aristotle called it philosophy [1922].

However, in the 14th century the term "natural philosophy" appears and philosophy is split into three parts: 'philosophy', theology (including natural theology) and natural philosophy (Fig. 1.2). Here, *'philosophy'* with single-quotation marks means philosophy in a restricted sense, the study of deep questions about humans (e.g., ethics and metaphysics). *Natural theology* is a branch of theology based on reason and ordinary experience, in contrast to revealed theology based on scripture and religious experience.[15] *Natural philosophy* is the study of (living and nonliving) nonhuman systems and non-religious issues, which is divided into two parts: one part without invoking God and another part with God invoked. The former is later absorbed into "science"; the latter falls into the "God of the gaps"[16] category and later becomes part of theology. A noted example of the latter is provided by Isaac Newton (1642-1727) who, knowing well that the stars always attract each other due to gravity, has invoked God's active intervention to prevent them from falling in on each others—a notion that was ridiculed by his competitor, Gottfried Leibniz (1646-1716) [Alexander, 1956, p. xvii].

Modern "science", beginning with Galileo Galilei (1564-1642) who died the year Newton was born, has blossomed rapidly in the last 400 years, especially in physics (see Section 1.7). After Galileo, a major player in the so-called Scientific Revolution, Newton's (deterministic) mechanics was so successful that people in the Enlightenment (1688-1789) wanted to make human matters a science, too [Porter, 2001]. They succeeded partially. Before the Enlightenment ended prematurely by the French Revolution (1789-1799), Adam Smith (1723-1790) published *The*

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[15] http://en.wikipedia.org/wiki/Natural_ theology (August 4, 2013).

[16] The concept of "God of the gaps", due to the evangelist Henry Drummond (1851-1897), suggests that gaps in *scientific* knowledge should be taken as evidence or proof of God's existence (en.wikipedia.org/wiki/God_of_the_gaps, Nov. 30, 2013). Since new gaps keep on appearing while science closes the old gaps, this argument will never fail [Lam, 2004]. For instance, when Newton's argument that it is God's hand that keeps the stars from sticking to each other is no longer needed after the expansion of the universe is established and explained by the Big Bang theory, Vatican embraces the Big Bang theory in 1951 before many scientists are willing to do [Linder, 2004]. And that is 14 years before Big Bang's final confirmation by Arno Penzias and Robert Wilson's experimental discovery of the cosmic background radiation comes in. The reason: Origin of the Big Bang is the new gap in science but Vatican has the answer: God did it.

Wealth of Nations [(1776) 1977], ushering in Economics, the first discipline in Social Science (Fig. 1.3).

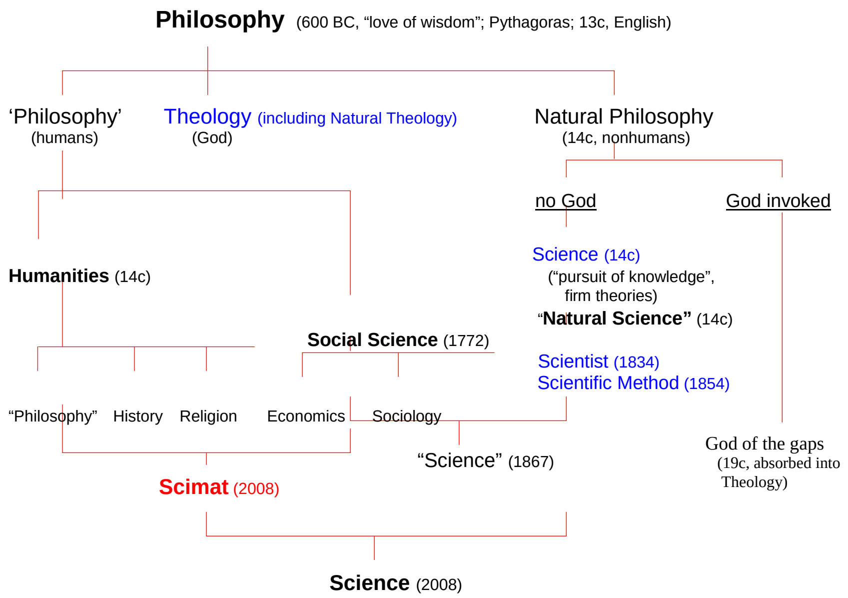

Fig. 1.2. A brief history of words, from philosophy to "science" and to scimat. "Philosophy" and "science", with double-quotation marks, correspond to philosophy and science, respectively, in their present, restrictive use (see text). The god-invoked part in natural philosophy is huge and frequently motivates the basic assumptions (such as Newton's absolute space) adopted by individuals working on the no-god part [Henry, 1997, pp. 73-85]. The year of 1834 for scientist comes from the Webster dictionary while 1840, attributed to William Whewell, appears in [Williams, 1983, p. 279].

By 1840, with enough number of people working full time in "science" the English scientist and theologian William Whewell (1794-1866) felt the need to coin the word "scientist" to describe these professionals; he was inspired by the word artist. After all, arts have been in existence long before science does, for at least 35,000 or perhaps a million years [Lam, 2011]. And the word scientist was not fully accepted until the early 20th century [Ross, 1962].

1687 Newton's *Mathematical Principles of Natural Philosophy* published

1688 Enlightenment begins

1762 Probability used in gambling and insurance business

1776 Adam Smith (**Economics**; *The Wealth of Nations*)—birth of **Social Science**

1789 Enlightenment ends

1812 Pierre-Simon Laplace (*Analytical Theory of Probabilities*)

1844 Auguste Comte (**Sociology**)

1859 Probability used in Darwin's evolutionary theory and Maxwell's kinetic gas theory —first time in science

Fig. 1.3. Enlightenment, Social Science and probability theory. The Enlightenment (1688-1789) aims to make a "Science of Man", which succeeds in creating Social Science but fails with the humanities. The reasons: (1) Human matters are not deterministic like in Newtonian mechanics but are probabilistic; (2) the necessary tools of a probabilistic science were not yet there [Lestienne, 1998].

Somehow, the word "science" in its present usage (written with double-quotation marks in this chapter) was not in place until April, 1867 [Harrison et al, 2011, p. 2] even though the word science, as remarked above, appeared already in the 14th century. "Science" means the sum of "Natural Science"[17] and Social Science, after 'philosophy' split into two parts in 1772: the humanities and social science. At this point, the assumed existence of God is confined entirely to Theology.

"Natural Science" differs from natural philosophy in that all theological and metaphysical considerations are excluded in the former but not necessarily in the latter. By these definitions, Newton was doing neither "science" nor "natural science" but natural philosophy. [18] However, we are so fond of Newton that we want to make him one of our own, a "scientist." The way to do that is to retain only parts of his book *Mathematical Principles of Natural Philosophy* (1687) in which

[17] In this chapter "natural science" with quotation marks means the science of nonhuman systems, the conventional definition. We prefer to call natural science the "science of all things in Nature"; i.e., science = natural science, by scimat's definition [Lam, 2008a].

[18] As confirmed by private documents and personal papers which became known since 1936, for Newton, religion and science were two inseparable parts of the same life-long quest to understand the universe. See PBS's NOVA program "Newton's dark secrets" (www.pbs.org/wgbh/nova/physics/newton-dark-secrets.html, Sept. 1, 2013), and also [Buchwald & Feingold, 2013].

God is not mentioned, notably, the mathematical description of the three laws of motion and the law of gravity, as we are doing it today in every physics textbook.

Presently, “natural science” consists of physics (including astronomy), chemistry, biology and Earth sciences (e.g., geology and atmospheric science). Social science consists of economics, sociology, psychology, linguistics, law, anthropology (which could include archaeology), etc., while the humanities are made up of “philosophy”, religion, history, [19] arts (e.g., literature, visual arts and performing arts), languages, etc.

However, as shown elsewhere, this historical classification is unreasonable and unscientific [Lam, 2008a]. It is harmful to the healthy development of not just the humanities but also of social science and physical science. Since the humanities, social science and medical science are all about humans a logical and systematic approach would be to group them together in one (umbrella) discipline—*scimat*.

1.6 Scimat 2: Science, Scientist and the Science Room

With the historical developments in mind, here are the new definitions of science and scientist proposed by scimat, followed by an introduction to the Science Room.

1.6.1 *Science Defined*

According to scimat, *Science is humans’ pursuit of knowledge about all things in Nature, which includes all (human and nonhuman) material systems, without bringing in God or any supernatural*. Some explanations are in order.

1. The pursuit of knowledge is the common denominator among philosophy, “philosophy”, “science” and science (Fig. 1.4). “Pursuit” here means earnest and honest research aiming to find out what and why.

[19] Note that history is sometimes classified as social science. It depends on the scientific level achieved in the discipline as conceived by the classifier [Lam, 2008a].

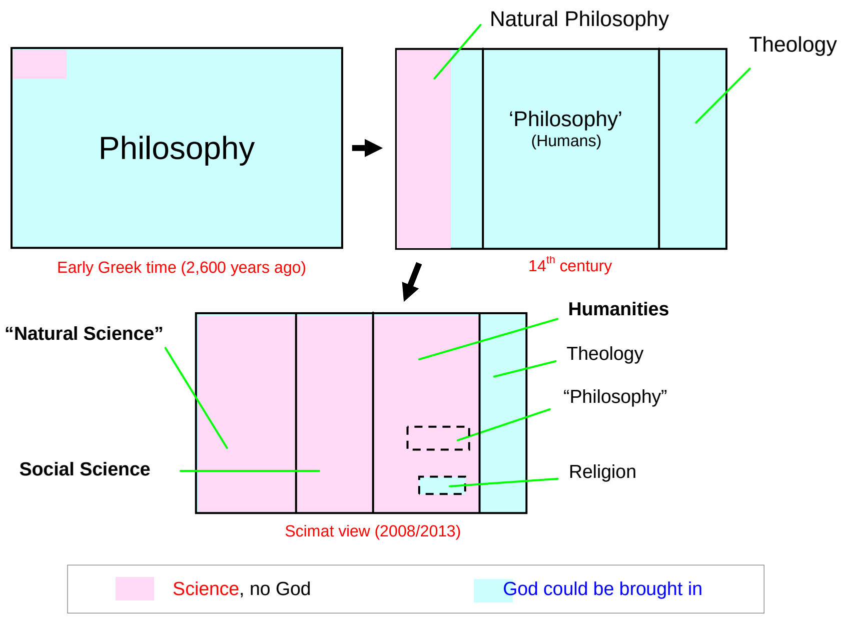

Fig. 1.4. Splitting of the discipline Philosophy in the last 2,600 years and the retreat of God in the disciplines over time (based on Fig. 1.2). The domain of Science, defined as humans' research in understanding Nature (human and nonhuman systems) without bringing in God/superstition, exists within the single discipline of Philosophy at Thales' time, the early Greek time. Science expands to about half of the discipline Natural Philosophy in the 14^{th} century while Philosophy reduces to 'Philosophy', which further shrinks to "Philosophy" as we know it today (see text). The distinction between Religion studies in the Humanities from Theology is that God's existence is not assumed in the former but in the latter.

2. Nature here, after Darwin and Einstein as discussed in Sections 1.3 and 1.5.1, includes all the material systems—the human system and all (living and nonliving) nonhuman systems. It is identical to the Universe.

3. By excluding God in the scientific process we are in disagreement with philosophy but in agreement with modern "science".

4. That God is excluded is based on two considerations: (1) God, if exists, is beyond Nature since, e.g., according to the Bible, he creates everything. (2) God is a "game stopper." For example, if you

got a funding from the US National Science Foundation (NSF) to find the mechanism of high-T_c superconductors and you reported that "God did it", NSF would ask you to stop the project and return the money immediately.

5. Scimat holds no position on whether God exists or not. The aim of science, from its beginning with Thales through Galileo and Newton, was never to challenge the existence of God. Religion and science is in conflict with each other only when religion does not retreat fast enough as science advances, and when either side over claims [Lam, 2004].

1.6.2 *Scientist Defined*

Following the definition of science in Section 1.6.1, here is scimat's definition of scientists: *A scientist is a person who honestly seeks knowledge about Nature without bringing in God or any supernatural*. In other words, a scientist is simply a *researcher* (res for short). Here are some remarks.

1. By this definition, apart from the natural scientists and social scientists, the humanists are also scientists, a consequence of the nature of Nature which includes human and nonhuman (material) systems.

2. If the humanists do not look like scientists to some people, it is because most humanists are still carrying out their research at the empirical level, similar to what Aristotle did long time ago. (See Section 1.7 for the three levels/approaches of research.)

3. Honesty is a must in real research. It refers to the researcher's honesty in collecting and handling data, and in reporting results. It also refers to the res' readiness in admitting mistakes when the res knows a mistake has been made, even though we understand that researchers, being humans, could find it difficult to do so.[20]

[20] Honesty appears in two of the five items in the Scimat Standard [Lam, 2008a, p. 27].

4. If one wants to, scientists could be separated into two classes: professionals and amateurs. Both could contribute to the progress of science, like in astronomy. The distinction should be of concern to the administrators in universities and funding agencies since it is their job to bet on the success chance of a researcher, and to the general public who has to decide whom to trust more (which is not a simple matter [Lam, 2014]). For scientists, the works of professionals and amateurs are judged critically alike anyway.

5. When one is enjoying the beauty of a rainbow in the sky, one is not a scientist. But when the same person starts to wonder where those rainbow colors come from she is taking the first step in doing science. If she goes further and records the shape of the rainbow and the distribution of the rainbow colors, she is doing science at the empirical level and becomes a scientist. When she tries to figure out, by theory or experiment, the mechanism of rainbow formation she is doing science at a higher level. If she succeeds she is a good scientist. If she is the first one in history who discovers the mechanism and gets it published, she is a "successful" scientist. Publish or not, the real joy in doing science is to have fun in discovering or understanding something in Nature.

6. Similarly, an artist is not a scientist when she is going through the motion of creating an artwork. But before or during the process, if she tries to figure out seriously by herself how to make things work, e.g., what techniques applied will achieve the effect she wants or how the receiver's brain (through the senses) can be stimulated the way she intends it to be, she is doing science and could be called a scientist [Lam, 2011, p. 24]. That is why Leonardo da Vince (1452-1519) is both an artist and a scientist even though he did not have formal training in science [Capra, 2007].

1.6.3 *The Science Room*

With scientists so defined in Section 1.6.2, we could also come around and say "science is what scientists do", borrowing the dictum from physics that "physics is what physicists do" [Lubkin, 1998, p. 24].

Science thus has two parts: (1) the results obtained by scientists, and (2) the process of doing science. (See [Warren, 2014] for an example.) Both parts evolve over time and are full of surprises (see Section 1.7).

To capture visually the essence of the above, we introduce the *Science Room* as a metaphor for science, which is represented by the right box in Fig. 1.5. For comparison, the conventional "natural science" room, which excludes the humanists and social science, is shown on the left. In the science room, over time, we see new scientists entering and old scientists leaving when they die or quit prematurely. Some, like Newton and Einstein, are bigger than others. Inside the room, results obtained by the scientists are kept, too. There are two kinds of results: those that are still in use (like the law of gravity, quantum mechanics and the special and general relativity theories) and those that are outdated (like Aristotle's mechanics). The latter are kept in a storage room (not shown). We do throw out junks (like alchemy[21]) from time to time.

The number of researchers inside the science room increases with time and also the size of the room. The former could be seen by counting the number of physicists: In ancient Greece the number could be in the tenths; 100 years ago, in the hundreds; today, 50,000 from the American Physical Society alone. The latter is evidenced by the rapid increase of research journals. Over all, the density of scientists in the room (i.e., number of scientists divided by room size) seems to become pretty high in the last 30 years, signaled by the difficulty of finding a worthwhile project and the "publish or perish" pressure felt by the professionals.

Observing the science room is like viewing a movie that never ends or not yet ends (we do not know which case it is), like the *Star War* series, with a new cast on the screen every 60 years or so (in historical time) if you happen to fall sleep intermittently. Like a good movie, science never repeats itself and is as intriguing as *War and Peace* while sometimes looks like the *Life of Pi*.

[21] Alchemy was a legitimate research topic in chemistry before the emergence of nuclear physics, only about 100 years ago. From nuclear physics we know that the identity of an element, like gold, is dictated by the number of neutrons and protons inside the nucleus of the atom. Thus, one can never obtain a gold atom from another metal by chemical method only, since chemistry only changes the electrons but not the nucleus.

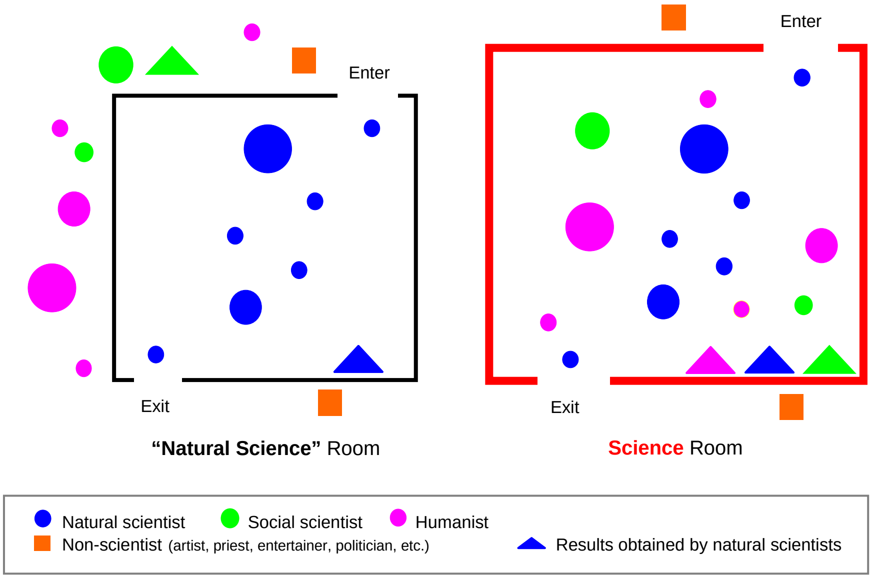

Fig. 1.5. The Science Room (right box) and the "Natural Science" Room (left box). The difference between the two is that humanists and social scientists (and their fruitful results) are included in the former but not in the latter. Note that "natural science" is mistakenly identified as science by many people. The walls of the room do not imply boundary of knowledge.

1.7 How Science Is Done

We here focus on the second part of science, i.e., how science was or is done.[22] A good way to explore this subject is to divide our discussion into two parts according to the subjects being studied, viz., simple systems and complex systems, since the methods of study though related, are sometimes quite different.

1.7.1 *Simple Systems*

Only a subset of nonliving systems and a small number of living systems could be considered simple systems (SS). They are the subjects studied

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[22] Only basic science will be considered below. Applied science and technology are quite different and are excluded.

in physics (including astronomy), earth science (excluding meteorology and climatology) and chemistry. Other living things such as vertebrate animals, humans included, belong to complex systems. [23]

The historical development of research in SS, particularly in physics and in later years, is rather well documented [Mason, 1962; Lindberg, 1992; Chen, 2009]. Essentially, it goes something like this.

1. Early period: from Thales to Galileo

With plenty of time and patience, ancient people *observed* and *recorded* what they saw in the sky about the movement of heavenly bodies and astronomy was born—science at the *empirical* level. Then with the aid of arithmetic and geometry, miraculously, they succeeded in predicting eclipses, for example, taking astronomy a big step forward.

After observation and data analysis, *theorizing* emerged, through guessing and logical thinking. Aristotle did it without experimentation about moving bodies, in the sky and on earth, and got it all wrong. Yet, the important point is that, in the absence of quantitative data, he was "right" at his time—an important criterion we use in judging scientists. Furthermore, through his classification works in biology, Aristotle did show us the need of empirical inquiry. His pioneering thinking and perceptions, the Aristotle tradition, was maintained for about 2,000 years after his death, helped by the ruling class. But this has nothing to do with Aristotle and is not part of the scientific process.

Archimedes was different. As the story goes, after the "eureka" moment triggered by water-level rising when he got into his bathtub, he run naked in the street and became the first streaker in history, which, luckily, did not become part of the scientific tradition. Importantly, after streaking, he did a few experiments in the lab and established the Archimedes' Principle about buoying bodies, which is still correct today [Hirshfeld, 2010]. Archimedes' Principle is an example of science at the *phenomenological* level, i.e., obtaining rules/laws about a phenomenon without knowing the mechanism.[24]

[23] Note that this demarcation is not sharp and is sometimes problematic. For example, a complex system, once understood, could become a simple system [Lam, 2008a].

[24] The mechanism behind the Archimedes' Principle is that water molecules keep on bombarding the body immersed in it as if the volume of water displaced by the body is

The Aristotle tradition was finally broken by Galileo.[25] It happened not because Galileo was much smarter than those before him but because he (1) picked simple systems (such as a small ball rolling down an inclined plane) to study, (2) did drastic and daring approximations in constructing theories (e.g., simplifying the body to a size-zero point particle), and (3) used detectors other than his bodily sensors to observe and record (e.g., using water fall as a timer in inclined plane experiments[26] and improving the telescope to look at the moon and beyond) [Lam, 2008a]. *Experimentation* became the hallmark of modern science; *mathematization*,[27] modern physics.

2. Modern period: four lessons

Everyone was happy, except for those living in the Vatican. And modern science flourished in every discipline (including biology and medical science in the complex-systems domain) except the humanities. Subsequently, for SS, two great theories, thermodynamics (1824) and Maxwell's electromagnetism (1873), were discovered. Near the end of the 19th century, it seemed to some that the "end of physics" has arrived. The sudden emergence of quantum physics in 1900, the black-body radiation experiments by Max Planck (1858-1947) [1900], was the party crasher. Newtonian physics no longer works and every able physicist was scrambling to find a new theory. Here is the *first* important lesson every modern scientist learns: *Nature is full of surprises and every dear theory may not be the final theory.*[28]

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still there. Since the existence of molecules was not confirmed until 1905 there was no way that Archimedes could figure out the mechanism behind his Principle.

[25] Attempts to move away from Aristotelian physics since the 6th century and before Galileo are discussed by Peter Berg [2012].

[26] See: "Galileo's inclined plane experiment" (galileo.rice.edu/lib/student_work/experiment95/inclined_plane.html, Dec. 1, 2013).

[27] Mathematization though desirable is sometimes over emphasized. Even within physics, Newton's third law of motion (action and reaction) and Thermodynamics' third law (it is impossible to reach absolute zero temperature in finite number of steps) are both written in words. Darwin's evolution theory, the most important result in biology, is expressed in words only, too.

[28] A similar case appeared at about the same time. Einstein in 1905 showed that Newtonian mechanics is a special case of his theory of special relativity when the body

As physicists are concerned, the next heart breaker showed up 57 years later: Madame Wu and her team discovered that parity is violated in weak interactions [Wu et al, 1957]. Parity is the mirror symmetry taken for granted by every physicist in the past, which says that if you set up an apparatus and put a mirror near it, construct a second apparatus according to what you see in the mirror, then the two apparatuses will give you identical results. Parity symmetry was regarded as basic as the time- and space-translational symmetries (which are still good, so far). Thus the *second* important lesson: *Never take* any *basic assumption for granted*.

Nature is kind to us. As if for compensation, in the same year of 1957, superconductivity discovered by Heike Onnes (1853-1926) 46 years ago was satisfactorily explained by the BCS theory proposed by John Bardeen (1908-1991),[29] Leon Cooper and Robert Schrieffer. Here is the *third* lesson: *If you wait long enough the answer* may *come*. However, it also shows that answer to your "prayer" does not come by keep on praying, but by more experiments and harder thinking. Also, Onnes did not live to see his discovery explained; the answer may not come within a lifespan. We kind of know this already since it took about 2,200 years for Democritus' atom to be confirmed, which is the case of theory preceding experiments while superconductivity is a case in reverse.

When the high-T_c superconductors were discovered in 1986 by Karl Müller and Johannes Bednorz and the Nobel Prize was awarded the next year—a lightning speed, quite a number of theoretical papers from famous authors were rushed to print in the prestigious physics journal *Physical Review Letters*. They turned out to be all wrong or unbelievable as more experimental results came in. In fact, instances like this happened before that a beautiful theory is not sustained by experiments and has to be rejected. The *fourth* lesson: Reliable *experimental results have the ultimate say in deciding the fate of theories in science*.

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moves slowly in comparison with light. That is, what we see as a high mountain in the knowscape turns out to be part of a higher mountain.

[29] Bardeen is the only person in history who won two Nobel Prizes in *physics*, for co-inventing semiconductor and the BCS theory of superconductivity [Hoddeson & Daitch, 2002].

3. Three remarks

1. Disciplines (or subdisciplines) in SS could be divided into two types: non-historical disciplines (e.g., condensed matter physics and particle physics) and *historical disciplines* (e.g., astronomy and geology). Control experiments are possible in the former but not in the latter. Then how do we study the historical disciplines? It is done by comparing data collected in the historical disciplines with knowledge gathered through controllable, repeatable experiments and confirmed theories in the non-historical disciplines. For example, by comparing the color spectrum of light coming from a star with those from known elements obtained in the lab we could tell what kinds of element existing in the star.

2. We never check *all* consequences/predictions from a hypothesis before we accept it as a confirmed theory. For practical reasons, we just do enough number of checking to convince ourselves that it is correct. And that is why an established theory *could* be broken later when new contradictive findings (usually experiments), if any, show up. *This strategy is what makes the rapid progress of science possible* in the last few hundred years. It is like how countries are being conquered: The invading army occupies some strategic cities/places and then the capital, never the whole country, and declares the job done; then they move on to the next country—Napoleon did that; Hitler did that. In science, we do the same in the knowscape (see Section 1.2) instead of the landscape. Consequently and occasionally, disturbance might suddenly burst out from a not-yet-occupied place in a conquered country. The conqueror would be forced to look back and suppress it or tolerate it. And that was what happened to the conqueror, the physicists, in the knowscape, in the case of parity nonconservation, except that they could not suppress it because parity nonconservation sits in the human-independent part of knowscape (see Fig. 1.1). Instead, they update their map of the knowscape.

3. The existence of atoms and the discovery of quantum mechanics made it possible to study many-body systems with a new approach, the *bottom-up* approach, called the “microscopic picture” in physics. This is the third approach apart from the empirical and the phenomenological approaches. For closed systems (such as gas in a jar) the theory to

accomplish this is Statistical Mechanics, which links the microscopic world to the macroscopic world. Computer simulations could also do the job, for both open and closed systems, but are less enlightening [Tuckerman, 2010]. Each approach or level of study complements and reinforces the level above it. Thus, results from the phenomenological level, if correct, will have to reproduce that from the empirical level and give more; results from the bottom-up level will do the same for the phenomenological level [Lam, 2002]. The availability of the three approaches is like that of the army, navy and air force in a war situation; you want to use all of them, if necessary, to do a quick and thorough job.

1.7.2 *Complex Systems*

Complex systems (CS) consist of nonliving (e.g., the weather or climate system) and living systems. The latter consists of humans or human-related systems (e.g., the economy) and other nonhuman, biological systems (e.g., plant, insect, fish, bird and coyote). A central, time-honored method of tackling CS (and SS) is the *Socrates Method* due to Socrates (470/469-399 BC), i.e., "to solve a problem, it would be broken down into a series of questions, the answers to which gradually distill the answer a person would seek".[30] Later methods are described below.

1. Difficulties and successes

Complications and difficulties in studying CS arise from five sources.

1. *The potential of chaos*. Chaos is the phenomenon that the future of a system depends sensitively on the initial conditions [Lam, 1998]. It could happen in a system of three bodies (like the Earth, Moon and a rocket) or of many bodies (like the weather, even though, in this case, only a simplified model of three variables has been proved).

[30] Source: en.wikipedia.org/wiki/Socrates (Jan. 1, 2014). The Socrates tradition of "questioning and debate", so central and fruitful in advancing (scientific) knowledge, has been continued in the West but less so in the East. In China, a similar tradition starting in the Autumn and Spring period (770-476 BC) was broken early on after Confucianism became the official state ideology of the Han Dynasty (206 BC-220) and has not yet been restored completely today.

Given a CS, the potential of chaos is always there but is hard to prove. That is why chaos is so frustrating.

2. *Heterogeneous complexity*. Complex systems are mostly heterogeneous, in terms of its components and interactions among them. For instance, the human body consists of a large number of different organs, interacting directly or indirectly with each other; in a society, no two persons are the same. (In contrast, in the SS of electrons, all electrons are identical to each other and every two electrons interact the same with each other.)

3. *Ethical limitations*. There are ethical problems in experimenting with living systems [Rollin, 2006]. That has been always the case with humans as the experimental object (with well-known exceptions like dealing with war prisoners). It extends to experiments with nonhuman animals in recent years. In other words, not every informative experiment (like human cloning) that could be done can be done, a problem not associated with simple systems. But it does not mean that we cannot and do not experiment with humans. Psychologists do that all time, harmlessly, by passing out questionnaires; hospitals try new drugs or new treatments on volunteers everyday. (See [Venter, 2013] for an interesting discussion on this issue.)

4. *Historical irreproducibility*. Human-related happenings are all historical, like in astronomy, which are irreproducible, with some exceptions in medical research. Therefore, on-site and real-time collection of data is rare except in mass demonstrations these days; even so, the data are always incomplete. And being humans, recounting of events by the participants, the so-called first-hand data, is subject to memory deterioration and intentional personal considerations. [31]

[31] This is demonstrated vividly in the so-called "Lee-Yang Dispute". The two Nobelists Lee Tsung-Dao and Yang Chen-Ning, in their personal recounts of how the parity nonconservation work was done, cannot agree on which Chinese restaurant that the crucial idea was raised, not to mention who is the one who raised it [Yang, 1983; Lee, 1986; Chiang, 2002; Zi et al, 2004].

5. *Temporal-spatial localization.* Since humans are influenced by culture and environment (in addition to human nature [Wilson, 1978; Machery, 2008]) research on humans based on observation/data from a local place for a particular historical period may not be applicable to other period or to humans in other countries or continents. Ignoring or ignorance of this localization feature results in over claim by humanists and social scientists, West and East. The problem is lessened but still present in the globalization era.

How and to what extent these complications could be overcome will be discussed below.

While the Holy Grail in CS research is to find the universal law(s), similar to the Second Law of Thermodynamics, say [Waldrop, 1992], it is very difficult to do so and fails so far. Instead, much progress has been made in the study of individual systems or classes of systems. Two "universal" organizing principles applicable to a large number, but not all, of CS are found: fractals and active walks [Lam, 2008a]. In lieu of general laws, computer simulations are heavily used [Mitchell, 2009] and techniques developed in simple-system studies are borrowed [Castellano et al, 2009]. The former overcomes the heterogeneous complexity since heterogeneity can be programmed easily in computers.

2. <u>Medical science and biology</u>

Among CS studies, the transdisciplinary medical science (more a basic science than applied) is the most developed despite and because it is about humans. Medical science could easily be the most important among all the disciplines, for the obvious reason. Its development benefits from early start,[32] continuous attention, and heavy funding.[33] It also benefits from the rapid advances in physics, chemistry and biology

[32] In the West, it started with Shamans and apothecaries' "niche occupation" of healing and ancient Egyptians' system of medicine before Hippocrates (c. 460-c. 370 BC) became the "father of Western medicine" in early Greek time. In the East, medical knowledge dates equally early (en.wikipedia.org/wiki/History_of_medicine, Dec. 30, 2013).

[33] In the US, the Fiscal Year 2012 funding for the National Institute of Health is $30.860 billion, which is 4.3 times of the National Science Foundation's $7.105 billion [Sargent Jr., 2013].

since the Scientific Revolution. But more importantly, medical research in the West keeps a very open mind and employs all the three research approaches (i.e., empirical, phenomenological and bottom-up) as soon as it is feasible to do so. (Drug designs at the molecular level, and genetic and stem-cell treatments under test are examples in the bottom-up approach.) Unfortunately, the same cannot be said about Chinese medicine [Lam, 2008a, pp. 32-33].

In biology, the discovery of evolution theory (1859) by Darwin and of double helix (1953) by James Watson and Francis Crick (1916-2004) leading to the prospect of synthetic life [Venter, 2013] demonstrates the workings of the empirical, phenomenological and bottom-up research approaches in successive action. For many people, what we are witnessing in biology is comparable to what happened in physics in the early 20th century. Moreover, the fact that Crick is a physicist-turned-biologist exemplifies the early trend of an s-res morphing into a c-res. (Here, s-res means a "researcher in simple systems"; c-res, in complex systems.)

3. Social science

As humans are concerned, it is in fact easier to study a large number of humans than a single human because many approximations can be made and justified in the former but not in the latter.[34] And that is why the scientific level achieved is much higher in social science than in the humanities.

Economics is the most developed discipline in social science not merely because it was the first discipline invented in this field, but because (1) a lot of data are generated and kept (think stock index), and (2) the financial reward is huge. The economy being a CS, it is not

[34] For example, when a windowless room with one door containing a large group of males (or females) inside is on fire, everyone will rush to the door to escape. As an approximation, the different thoughts going on in their brains could be ignored. And a strategy to avoid jamming the door could be designed from computer simulations by treating the humans as point particles with simple interactions. This kind of research that concentrates on common human nature (escape from fire) avoids the localization problem. Pedestrian modeling has been developed successfully into a science, with applications ranging from pedestrian trail formation in a German campus [Helbing et al, 1997] to crowd control in Mecca [Helbing & Johansson, 2010].

surprising that no universal theory about macroeconomics has yet been found, not to mention that no one is able to predict the rise or fall of a stock market. This is in contrast to the success of the meteorologists who are able to predict pretty accurately the *local* weather, also a CS, of the next day. The difference is that the equations involved are known in the latter (solved by supercomputers) but not in the former. We therefore see our top economists revising their "prediction" of the national economy from time to time, if not every day, which in fact is a good sign showing that they are honest scientists [Lam, 2008a, p. 28]. But then the question: If the economists fail so miserably, why is there a Nobel Prize given out every year in economics? Well, the Nobel Prize rewards the solution of individual, significant problems, which is possible even in CS.

There is a long string of successful stories of physicists making contributions in economics and finance [Weatherall, 2013]. But Wall Street has been blamed for hiring physicists who helped to bring down the global economy in 2008 [Patterson, 2010]. This is an issue of s-res morphing into c-res, unsuccessfully in this case. But that is because Wall Street has hired the wrong kind of physicists.[35] There are different kinds of physicists, like there are different kinds of engineers. If one wanted to design a new bridge, one would not go out and hire electric engineers to do the job; right?

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[35] The 2008 economic meltdown could be attributed to three causes: (1) the financiers themselves; (2) central bankers and regulators who failed to see it coming; and (3) the macroeconomic backdrop of low inflation, stable growth and plenty of cheap Asian money ("The origin of the financial crisis", *The Economist*, Sept. 7, 2013, pp. 74-75). The financiers part involves their hiring of mostly high-energy physicists, the "quants" [Derman, 2004], who helped to design financial "products" that were sold worldwide, making a lot of money for everyone before it collapsed. No one seemed to remember that for a "product" (like a toy for children) safety, called stability in physics, should be taken care of before you put the product in the market. In the expert's words, "the quants who devised the highly leveraged financial derivatives ignored systemic risk" [Stein, 20110]. And unfortunately, stability analysis is not part of a high-energy physicist's training. These days, the stability analysis is called "stress test" mandated by the government to the banks. Recommending Wall Street to hire more physicists [Weatherall, 2013] is not a bad idea, if only proper training/briefing is prescribed to these s-res before turning them into c-res and letting them play with real money. The case of physicists doing econophysics [Ball, 2006] is a different matter since they are just creating theory, not products.

Fortunately, there are also many successful examples of s-res doing fine in sociology.[36] And we see the emergency of a new field called Computational Social Science [Cioffi-Revilla, 2014; Epstein, 2014].

4. Humanities

The development in the humanities is lacking behind, due partly to the intrinsic complexity of humans as individuals but also to the inadequate scientific training of the researchers involved. Thus, it is uncommon that we hear people saying that the humanities cannot be part of science. They are wrong, for two reasons: (1) Many humanists mistakenly identify science with Newtonian mechanics; (2) the humanists ask the wrong questions.

The mis-identification of science with Newtonian mechanics started early (since the Enlightenment) and is still with us today,[37] due to the failure of science education and science communication [Lam, 2014]. Since each human is an open system (that exchanges energy and materials with the environment) and the factors that could affect a human or a group of humans cannot be completely account for, the human system is a *stochastic* system (i.e., probability/chance is involved). If one identifies science with the deterministic Newtonian mechanics then, of course, science is inapplicable to handle the human system. But scientific theory (physics in particular) and techniques dealing with both deterministic and stochastic systems are available (see Fig. 1.3 and [Lam, 2011]).

Given a stochastic system the question one should ask is not what will surely happen in the future but with what probability something may happen in the future [Lam, 2002]. For example, in History, the question one can ask about the longevity of a dictatorship is not in which year it will end definitely, but what is the chance it will still be there five years later, say. Surprisingly, amid all the contingencies and historical irrepro-

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[36] For example, Duncan Watts has a BS in physics, PhD in engineering and is now a professor of sociology at Columbia University; Dirk Helbing, PhD in physics, is Chair of Sociology at Swiss Federal Institute of Technology Zürich.

[37] See, e.g., *The Counter-Revolution of Science* by the economics Nobelist Friedrich Hayek (1899-1992) [(1952) 1979] and the philosopher Peter Winch's *The Idea of a Social Science and Its Relation to Philosophy* [(1958) 2008].

ducibility a *law* about the lifetime of Chinese dynasties has been found [Lam, 2006; Lam et al, 2010]. And an e-journal dealing with the theoretical and mathematical aspects of history from the scimat perspective [Lam, 2008c], *Cliodynamics*, has been published by the University of California since 2010. What this demonstrates is that human matters can indeed be studied scientifically (by going beyond the narratives), irrespective of all the complex thinking and so-called "free will" going on in humans' brains.

Recently, a DNA study of 1,000 descendents of Cao Cao, an important Chinese general in the Thee Kingdoms period (220-280), eliminates the possibility that Cao was the descendent of a famous aristocrat [Wang et al, 2013; Jiang, 2013]. This work showcases the bottom-up approach in history.

Studies at the empirical and phenomenological levels in the humanities have been going on for more than 2,400 years since Plato and Aristotle. What is new is that in the last decade or so we see the bottom-up approach being advocated by the humanists (including some in English Literature, e.g., [Hogan, 2003]) themselves. This includes the emergence of *Neurohumanities* and efforts to understand human matters from the cognitive and evolutionary perspectives (see [Lam, 2011] for details). As an example, the neurobiologist and Nobelist Eric Kandel's *The Age of Insight* [2012] shows how the Vienna portraiture from 1900 to present could be understood at the three research levels.

Even in "philosophy", the toughest discipline where metaphysics is studied, one finds serious attempts by its practitioners to do their trade with non-traditional methods. For instance, in addition to Neurophilosophy that tries to solve the mind/brain problem using cognitive science [Churchland, 1986; Churchland, 2007], Experimental Philosophy tries to solve philosophical questions by using empirical data (usually from surveys of ordinary people) [Knobe, 2011; Knobe & Nichols, 2008]. All these are very encouraging, from the scimat perspective.

5. <u>Living with uncertainty</u>

For inanimate CS, the existence or absence of chaos can be ascertained in rare cases while oversimplified models are used (e.g., the threevariable climate model of Edward Lorentz (1917-2008) [1993]). But the human system is different; we have no choice but to live with the potential of chaos. Similarly, the human system's intrinsic probabilistic nature cannot be circumvented. Worse, a small but finite probability for something to happen does not mean that it would not happen; on the contrary, it means it *could* happen. Some probabilistic events (like not winning a lotto) if happen, would be harmless; but others (like global warming or the danger of genetically modified foods) could have dire consequences.

It is true that consilience (i.e., the convergence of evidence) implies a conclusion is most likely to be correct [Wilson, 1998]. But since Nature is subtle and full of surprises, "most likely" means it is not safe to assume it is 100% valid. Uncertainties, big or small, are with us everyday.[38]

The research history of simple and complex systems shows that there exists no such thing called the *Scientific Method* [Bauer, 1994] even though this term is invoked frequently by scholars [Thurs, 2011; Gower, 1997] and laypeople alike, if the method means a recipe of steps that guarantee success when followed, like in the case of a cooking recipe. Instead, what we have are equally valuable, viz., "scientific experience" and "scientific tradition". The reason behind all this is that research is a very complex process that does not yield easily to a simple summary. Besides, there are emergent properties manifested on many levels in a given system which could be attacked through one or all of the three research approaches; there is no need for an oversimplified, universal scientific method. The absence or de-emphasis of a scientific method is exemplified by the criterion used in the Nobel Prizes in the sciences, which are awarded for confirmed, grand discoveries, irrespective of the method and reasoning used. In fact, if there was really such a powerful scientific method, research would be pretty boring and

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[38] For example, whenever we set foot on the street (or even the sidewalk) we run the risk of being hit by a car. It does happen. In the first three months of 2014 in San Francisco, six pedestrians lost their lives this way (*World Journal*, Mar. 21, 2014, p. B1). The same goes for driving. Being careful yourself is not enough.

we would see many creative scientists walking away—doing art or go fishing.

1.8 The Essence of Science

About science the three features listed here, though incomplete, are the most important.

1. Science advances and lives with approximations

It is a myth that "exact science" ever exists, for the following three reasons. (1) Every theory constructed turns out to be an approximated theory. First, a theory is the model of the real thing; e.g., in Newton's laws of motion a body is approximated by a point mass. Second, the theory is the approximation of a bigger, later theory; e.g., Newtonian mechanics is an approximation of Einstein's theory of special relativity. The Standard Model in particle physics is the low-energy approximation of something not yet known [Weinberg, 2011]. (2) Even if a theory is exact, the solutions obtained usually involve approximations because exact solutions are rare.

(3) Even if the theory and the solution are both exact, it still has to be checked by experiments. And experiments involve instruments and measurements which always have finite resolution. For example, to check the equation $A = B$ we measure each quantity and try to show that the left-hand side equals the right-hand side. But let us say our measurements give $A = 2.5 \pm 0.1$ and $B = 2.5 \pm 0.1$, we can only conclude that $A = B$ within experimental uncertainty (due to that $\pm$ 0.1). Measurements' unavoidable finite resolution prevents a rigorous proof of any theory.

In other words, *science never proves anything, rigorously speaking* (in the mathematical sense of proof). There is nothing absolute and final in science, with profound implication for "philosophy" [Lam, 2014]. Thus, there *could* be room for improvement in any theory, which is known for sure when the new improvement appears. Approximation works because, like when lost in a forest, a rough map is all one needs to get out of the forest. More importantly, as mentioned above, it is precisely due to the use of approximations that science progressed so fast in the last few hundred years.

Science lives and thrives with approximations. Coupled with what we say in Section 1.7.2, we humans (i.e., everybody, scientists and non-scientists alike) simply have to go on living with uncertainty, more *wisely* and *humbly*.

2. Scientists are humans

Scientists are humans, like you and me.[39] Most if not all, including Einstein [Kennefick, 2005], do make mistakes [Youngson, 1998; Livio, 2013]. But some, like Newton, are not like you and I. They are not just brighter, but are tormented and darker—not entirely their fault.[40] Some genius not just contributed more but suffered more, too. And humanity owes them a lot.

3. There is always the Reality Check

If science is not and could not be exact, and scientists are just humans, why should anyone take science seriously? Everyone should, for two reasons: (1) *Science delivers*. We owe our air conditioning and cell phone plus many other goodies to science. Science is valued because it works. (2) *Science is the best game in town*. As Newton [(1730) 1952] puts it, "And although the arguing from Experiments and Observations by Induction be no demonstration of general Conclusions; yet it is the best way of arguing which the Nature of Things admits of".

Why is science able to deliver? It is because it has to pass the *Reality Check* (RC), like every legitimate driver has to prove herself by passing the road test. Reality check means "confirmed" by experiments or practices, or, at the minimum, is consistent with established data. Social theories, due to the imprecise and incomplete data collected, are hard to be 100% confirmed [Lam, 2008a]. Reality Check is the *necessary*, crucial step for a theory to be recognized as part of the knowscape. It is the RC that makes scientific knowledge unique among all forms of "knowledge".

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[39] See [Kevles, 1987] and the many biographies of scientists.
[40] See PBS's "Newton's dark secrets" (www.pbs.org/wgbh/nova/physics/newton-dark-secrets.html, Sept. 1, 2013).

Among the RCs, the *Cell Phone Test* (CPT) stands out because the working of a cell phone depends on the validity of a large number of theories (Fig. 1.6). Any new theory, if it conflicts with what are behind the working of a cell phone, has to explain why and why it is better. A good answer would be the new theory contains the old ones as special cases. We strongly recommend the CPT to advocates of anything new.

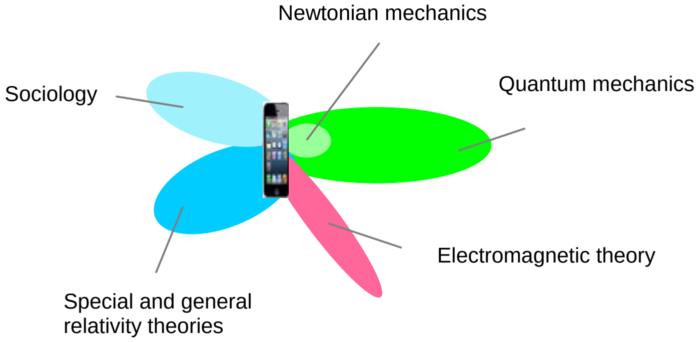

Fig. 1.6. Cell Phone Test: established, interrelated theories behind a cell phone. The working of a cell phone depends on Maxwell's equations, quantum mechanics, semiconductor theory, general relativity, and the sociological fact that there is enough number of humans who want to interact with others.

1.9 Scimat 3: Q & A and Ramifications

Scimat's spirit and essence as well as the action plan in the immediate future are summarized in Section 1.9.1. Some of the ramifications, including a new perspective on antiscience and pseudoscience, are discussed in Section 1.9.2.

1.9.1 Q & A

Q: What is scimat?
A: It is a new discipline that recognizes "everything in Nature is part of science".

Q: What do you mean by Nature?

A: Nature includes all living and nonliving material systems, humans in particular.

Q: What do you mean by Science?
A: Science is humans' pursuit of knowledge about all things in Nature, which includes all human and nonhuman systems, without bringing in God or any supernatural.

Q: What is scimat's position on God and religion?
A: Scimat holds no position on whether God exists or not. Personal choice of religion is respected.

Q: What are the topics that scimat covers?
A: All topics related to humans. That is, all the topics in the humanities and social science.

Q: Why does scimat put its emphasis on the humanities?
A: Because social science has been recognized as science but not yet the humanities.

Q: Why are the humanities so important?
A: All the world tragedies (poverty, war, race cleansing, injustice, corruption, etc.) are human-dependent matters and could be traced to the underdevelopment of the humanities in the last 2,400 years since Plato and Confucius.

Q: What new method or new tool is used by scimat in its research?
A: None. Scimat advocates the use of any method or tool that is available and applicable as long as honesty and ethics are respected. Reason: Scimat is about the search for knowledge which knows no boundaries and no pre-determined routes.

Q: Anything more?
A: Well, we do point out and want to emphasize that in any discipline there are three approaches—empirical, phenomenological (i.e., without knowing the mechanism) and bottom-up; they supplement and reinforce each other, like army, navy and air force in a war situation. This is well known in nonhuman studies but less so in the humanities.

Q: Then what is new about scimat?
A: The concept that "all human-dependent matters are part of science" is new.

Q: So what?
A: Humanity advances through new concepts. Examples: "All men are born free" brings down slavery; "all men are born equal," royalties and totalitarian regimes; "all women are born equal, too," restrictions on women's rights in education, employment and voting.

Q: Will all the world problems be solved if enough number of people become scimatists?
A: We don't know. But, in our judgment learned from history, scimat is the best, practical way to make the world better and more peaceful since people would be more enlightened and, hopefully, act more rationally, *humbly* and kindly toward others and the environment. The next step is to educate the decision makers.

Q: What is scimat's action plan for the future?
A: To set up 100 scimat centers worldwide, to ensure the development of and sustain scimat's ideals. The first step is to set up one such center. What the center can do is spelled out in "The *Science Matters* Program and a Proposal" (see: www.sjsu.edu/people/lui.lam/scimat).

Q: How can I help?
A: Buy this book. And tell others to do so.

Q: How can I help more?
A: Buy the other two books in the Scimat Series: *Science Matters* (2008) and *Arts* (2011). Or, ask your library to do that; better, do both.

Q: How can I help much more?
A: Be a sponsor or co-sponsor of our next scimat conference. It takes 20,000 USD to run a good conference, 10,000 USD to run a conference.

Q: What if I can't wait?
A: Gather, from your friends if necessary, 50,000 USD and contact the author: lui2002lam@yahoo.com. We will help to set up a Scimat

Center in the university or city of your choice (tax exempt in the US). The Center could be named after the person you prefer if more money is donated.

Q: How can I help without money involved?
A: Visit the scimat website and help spread the word.

Q: What is scimat's take home message?
A: Humanities are part of science.

1.9.2 Ramifications

Important implications of scimat including a new answer to the Needham Question have been given before [Lam, 2008a]; here are more.

1. Since science includes the humanities, "philosophy" in particular, the early Greek philosopher Socrates was a scientist, too. Socrates as a social and moral critic while practicing his philosophy became a "gadfly" of the state, in Plato's words. He was sentenced in court for "guilty of both corrupting the minds of the youth of Athens and of impiety (not believing in the gods of the state)" and persecuted.[41] Thus, the c-res *Socrates was the first "martyr of science"* while the s-res (in astronomy) Giordano Bruno (1548-1600) was the second one.[42] The former was ordered to swallow poison; the latter, burned at the stake.

2. Does antiscience really exist? It depends on how science is defined. Let us consider marriage and antimarriage first. The conventional definition of marriage is that (1) it is a legal piece of paper, (2) signed by a woman and a man (who promise to take care of each other). Antimarriage usually refers to the objection of item 2 but not item 1; i.e., an antimarriagist advocates that the legal paper could also be signed by a woman and a woman, or a man and a man. Similarly, it is hard to imagine anyone in her right mind would object to doing science per se unless science is defined in the narrow sense, i.e., science is about nonhuman systems only. *Antiscience* usually refers to the objection of certain things such as doing certain kinds of scientific research and the

[41] en.wikipedia.org/wiki/Socrates (Jan. 1, 2014).
[42] en.wikipedia.org/wiki/Giordano_Bruno (Jan. 1, 2014).

abuse of science; instead, putting the money in education, fighting poverty and human development are recommended [Holton, 1993]. All these debates are about over claims by some scientists and humans' choices, e.g., the priority and reallocation of resources. These are legitimate, human-dependent matters. Thus, if science is to include all human matters as it should, according to scimat, there is no such thing as antiscience. On the other hand, there does exist antiscientists—those who commit science frauds (in the humanities and other sciences) since they violate the first rule in doing science, i.e., being honest in their research.

3. The *science-pseudoscience demarcation* is a complex issue [Shermer, 2011] which is less about science per se [Pigliucci & Boudry, 2013] but more about the competition for attention, prestige and resources [Gordin, 2012]. In particular, the debate on "intelligent design" (ID, a form of creationism) being science or pseudoscience is due to the fuzzy definition of science used, either in the media or in court [Shermer, 2006]. If God is explicitly excluded from the definition of science, as in scimat, this debate would never happen, case closed. In fact, ID could be discussed in "philosophy" or theology classes. The problem for the ID advocates, of course, is that in America's public high schools, there is neither "philosophy" (unlike in France) nor theology classes. If religion-government separation works (in the US at least), why not religion-science separation?

4. The objectivity in and the reconstruction of past "reality" through historical narratives are considered impossible by some historians [Hayden, 1973] and deconstructionists [Derrida, 1976] because, they argue, the exact meaning of any writing is undecidable. These and other postmodern attacks led to a crisis in the history profession in the 1990s [Gilderhus, 2000; Evans, 1997]. That language, spoken or written, is an imprecise mode of communication is a well-known fact. The good news is that since science advances by approximations, history—a branch of science also does not need to be exact in its narratives, research at the empirical level. (See also [Lam, 2008c].)

1.10 Discussion and Conclusion

Here are some discussions and elaborations concerning what are written above.

1. The most negative effect derived from misconceptions about science is that the topics studied in the humanities are excluded from the domain of science. If that was the case, Aristotle would have two hats to wear. He would don on the "science hat" while he was studying the cosmos, plants and animals; and the "non-science hat" while he was talking about human affairs. Won't that drive Aristotle crazy? You bet!

2. A positive effect of recognizing humanities as part of science, apart from helping to reduce or eliminate human tragedies (such as ideological massacre or hunger), is to reverse the rapid decline of enrollment in humanities in the universities. According to a newspaper report (in San Jose Mercury News), from 1966 to 2009, the percentage of students receiving bachelor degrees in the humanities at Stanford University drops from 37% to 11%; for all institutes in the US, from 17% to 7%. By treating themselves as part of science, the humanities will attract science-inclined students who normally would opt for "natural science" and engineering for the wrong reasons; these students will also help to raise the scientific level of the disciplines and create more jobs.

3. We have come a long way to be able to declare freely that humans are animals made up of atoms. Only about 400 years ago, scientists in Naples were arrested and tried for maintaining "that there had been men before Adam composed of atoms equal to those of other animals" [Jacob, 1997, p. 28].

4. The existence and scale of the god-invoked part in natural philosophy and its influence on the no-god part is often overlooked by scholars in science. Consequently, some experts simply identify, wrongly, natural science with natural philosophy while only the no-god part of the latter should be identified as the former. (For more see [Cunningham & Williams, 1993, p. 421].)

5. Even some practicing scientists' characterization of today's science is wrong. When they say that controllable and reproducible experiments are a must in science they forget all those historical (scientific) disciplines like astronomy and archaeology (see Section

1.7.1). An example is provided by the chemist Igor Novak [2011, p. 31] when he says, “Science uses reproducible, controlled experiments (as part of the ‘scientific method’) and draws conclusions on the basis of experimental results *and* logical reasoning *alone*” (emphasis in original). And, of course, he excludes social science, not to mention the humanities, in his use of the word science.

6. Some experts identify science with modern science. This choice causes unnecessary confusion and even some inner contradictions. If only modern science is science, what is the Archimedes’ Principle which is still being used today? This problem could not be overcome by dividing the development of science into three levels, viz., prescience (e.g., Aristotle), parascience (Newton) and euscience (Galileo), as done in [Jaffe, 2010]. If so, Thales would be the “father of prescience”. And it is odd to label Newtonian mechanics as parascience; it is good science, a special case of Einstein’s relativity which in turn could be the special case of something else in the future. A better way is to view Aristotle’s physics which was correct at his time but is obsolete today as one of the numerous outdated theories in the history of science. (For more see [Lam, 2014].)

7. Scientism has different definitions.[43] But essentially, *scientism* implies the universal applicability of the scientific method and the supremacy of scientific knowledge. Scimat is not scientism because we do *not* believe in the existence of a scientific method (see Section 1.7) and we do respect people’s right to seek knowledge by any avenue they happen to choose as long as it is safe and ethical. We just say that judging from past history, science is the *most likely* way to succeed, from making a cell phone to curing cancer and to lessening humans’ sufferings. In fact, science guarantees nothing and promises nothing except in those well-understood simple systems (like water boiling at 100 ^{o}C). For unsettled problems in simple systems (like high-T_c superconductors) science thinks it can solve the problem given enough time; for complex problems related to humans (like love, ethics and soul) the promise of science remains a promise, until it delivers. Thus, scimat

[43] en.wikipedia.org/wiki/Scientism (Jan. 2, 2014).

does not belong to what Harry Collins calls the "first wave of science studies" [2014].

8. After this chapter is essentially completed, an interview of the Nobelist David Gross by Peter Byrne [2013] came to our attention. The non-finality of any scientific theory and scientists' willingness to abandon what they cheered and toiled with for a lifetime when convinced otherwise (described in Section 1.7.1) are concurred by Gross when he says, "We were all looking for the next overthrow, and we were willing to sacrifice existing theories at the drop of a hat". Other common or not-so-common believes presented above in this chapter are consistent with Gross' sayings, too:

> New discoveries tend to be intuitive, just on the borderline of believability. Later, they become obvious. … A scientific "frontier" is defined as a state of confusion. … Philosophers who contribute to making physics are, thereby, physicists! … The public generally equates uncertainty with a wild guess. Whereas, for a scientist, a theory like the Standard Model is incredibly precise and probabilistic. *In science, it is essential never to be totally certain*. And that lesson is hammered into every scientist and reader of history. Scientists measure uncertainty using probability theory and statistics. And we have comfort zones when making predictions, error bars. *Living with uncertainty is an essential part of science*, and it is easily misunderstood….. [T]he human mind is a physical object. It's put together by real molecules and quarks. (My italics.)

Nevertheless, as stated in item 2 of the *Scimat Standard*, "We will not quote anyone's writing to support our own argument" [Lam, 2008a, p. 27]. The quotes by Gross should not be taken as evidence that the arguments in this chapter are correct, which can only be reached through the reader's own judgment.

9. Scimat provides the key in solving the two-culture problem [Lam, 2008a]. It is also the theoretical foundation of scientific culture studies [Liu & Zhang, 2014] because it provides a unified perspective and basis in describing human matters, and similarly for general-education courses which try to educate students on both the humanities and "science".

10. The Enlightenment's aim of making a science of humans was partially successful; it created social science but fails with the humanities (Section 1.5.2 and Fig. 1.3). Scimat could be viewed as *Enlightenment 2*, continuing with what the Enlightenment left unfinished but smarter.

11. In America, the way to raise the scientific level of the humanities is to ask the National Endowment for the Humanities (called the National Humanities Foundation, after NSF, in the planning stage) *and* NSF to fund more interdisciplinary research that merges the humanities with the "sciences".

Take home message: Science's characteristics are its secularity and the reality check. The necessary Reality Check is what makes science useful and distinctively different from humans' other types of inquiry.

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