What to Communicate in Science Communication

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What Is Science?
What Is Science?

Wu Guosheng

90% correct
Science is the study of Nature

Nature includes all material system (made up of atoms).

Humans is a material system (evolved from simple living systems).

The study of things in Nature (humanities included) is part of science!

But this understanding could be reached only in the last 100 years of so, after Darwin’s theory of evolution (1859) and Einstein’s Brownian motion paper (1905) proving the existence of atoms.

Early stage of science (starting with Thales) involves observations and speculations; systematic approach appears only in the later, mature stages (in the modern science period of the last 400 years since Galileo).

Ethics, Arts, Science are the 3 pillars supporting modern civilizations.
Rainbow and You

- Admiration only: Not yet a scientist
- Ask how the rainbow colors are produced: First step in becoming a scientist (but not yet)
- Record rainbow’s shape and color distribution: A scientist at the empirical level
- Do theory or experiment to understand the formation mechanism: A scientist at the phenomenological level
Rainbow formation: Science at phenomenological level

- No God
- Rational thinking
- Need to ask why
- Consistent with lab experiments
Three Research Levels in Science

<table>
<thead>
<tr>
<th>Empirical</th>
<th>Phenomenological</th>
<th>Bottom-Up</th>
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<tbody>
<tr>
<td>Gas law:</td>
<td>From “conservation of momentum” and a few simple assumptions about the material</td>
<td>1. Kinetic gas theory  [can re-derive the above equation and relate the parameters ($\rho$, $\mu$) to molecular properties]</td>
</tr>
<tr>
<td>$P V = k T$</td>
<td>(without the knowledge that gas are made up of molecules), can derive Navier-Stokes Equation:</td>
<td>2. Monte Carlo simulations  (starting from molecules)</td>
</tr>
<tr>
<td></td>
<td>$\rho \left[ \frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} \right] = - \nabla p + \mu \nabla^2 \mathbf{v} + \mathbf{f}$</td>
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Thales (c 624 - c 546 BC)

- Father of science
- Everything is made of water

Guanzi (c 645 BC)

- Chinese philosopher
- Everything originates from water

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地者，万物之本原，诸生之根荄也。美恶、贤不肖、愚俊之所生也。水者，地之血气，如筋脉之通流者也。故曰：水，具材也。
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- Thales: Asks *why* and gives explanation
- Guanzi: Does not ask why

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- The basic step in science is to ask why
- The Socrate’s Method in science: Keep asking why

Not asking why is the major reason that ancient Chinese science remains at the empirical level (called Natural History in West and 博物学 in Chinese), without going deeper into analytic science like in the West.

Not asking why (encouraged by emperors) is part of the Chinese culture starting from ancient times since Confucius.
Theory means a confirmed hypothesis.

- Every theory is an approximation of “reality” (or a better theory later).
- For an “exact” theory, it is rare to find exact solutions.
- An equation is confirmed by measuring the quantities and showing that the left-hand-side of eq. is equal to the right-hand side.

\[ F = ma \]

But every measurement has uncertainty (called error) dictated by the apparatus used.

And so the equation can only be confirmed approximately.

- It is a myth that “exact science” ever exists.
- **Science never proves anything, rigorously speaking** (in the mathematical sense of proof).
- Science lives and thrives with approximations.
Why science is valued

• Science delivers.
• Science is the best game in town.

Why science can deliver

• Reality check means “confirmed” by experiments or practices, or, at the minimum, is consistent with established data.
• It is the RC that makes scientific knowledge unique among all forms of “knowledge”.

The cell-phone check
Defining Science
Birth of Disciplines and Science

Philosophy (500 BC, “love of wisdom”)  

‘Philosophy’ (Humans)  
Theology (God)  
Natural Philosophy (Nonhumans, 14c)

Humanities (14c)  

Social Science (1772)  
“Philosophy”  
History  
Religion  
Economics  
Sociology

“Science” (1867)  

Scientist (1834)  
God of gaps (19c, absorbed in Theology)

Medical Science not belongs to ‘Philosophy’ or Natural Philosophy. It belongs to Scimat, which includes everything related to humans.

Scimat (2007/08)  

Science (2007/08)
Religion

Existence of God not assumed

Natural Philosophy

Early Greek time (2,600 years ago)

Theology

14th century

Philosophy

‘Philosophy’ (Humans)

Social Science

Humanities

“Natural Science”

Theology (existence of God assumed)

“Philosophy”

Religion (existence of God not assumed)

Scimat view (2008/2014)

Science, no God

God could be brought in

Scimat ( = humanities + social science + medical science)
Science is humans’ (earnest and honest) pursuit of knowledge about all things in Nature (which includes all human and nonhuman material systems) without bringing in God or any supernatural.

Humanities vs “Natural Science”

• “Natural science” did enlighten our understanding of Nature (e.g., Big Bang), make our living easier (cell phone), and help prolonging our life (for good or bad).

• But it is the humanities that determine our quality of life (e.g., to pollute or not to pollute) and bring us genuine happiness (human relationships, arts).

• Also, it is humans (through decision making, a branch of humanities) who controls the use of “natural science”.

• And that is why the humanities (the disciplines) are more fundamental and important than “natural science”.
Scimat (人科), invented by Lui Lam in 2007/2008, is a new multidiscipline that focuses on the science of humans.

Science = Natural Science

= Science of nonhumans + Science of Humans

“Natural Science”

Scimat

Humanities + Social Science + Medical Science

Scimat Website: www.sjsu.edu/people/lui.lam/scimat
• 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.

• Uncertainty is unavoidable in human matters.

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**One culture, two systems, three levels!**

• One scientific culture
• **Two kinds of systems** *(simple and complex)*
• Three research levels *(empirical, phenomenological, bottom-up)*
What Not to Communicate
Wrong: Science is about the systematic study of repeatable and controlled experiments.

Correct: The backbone of science is the collection of (interrelated) theories and controlled experiments; historical sciences (like astronomy and paleontology) advance by comparing their findings with results from controlled experiments.

Wrong: There is a set of well defined procedures making up the Scientific Method.

Correct: Scientific Method in this sense does not exist. Science is about open-mindedness, honesty, earnest, admitting errors, and peer reviewing/checking. There is “scientific tradition” or “scientific experience” but no “scientific method”.

Wrong: Science is a social phenomenon (Hitler).

Correct: The science process is human dependent (and a social phenomenon) but the end result of nonhuman systems (like law of gravity) is human-independent.
Wrong: Important scientific laws or theories are always expressed in mathematical equations.

Correct: Not true, even in physics. Example: Third Law of Thermodynamics (It is impossible to reach the absolute zero in a finite number of steps). Also: Darwin’s Evolutionary Theory (The fittest survives).

Wrong: Scientists are always right.

Correct: Scientists are humans. Even Einstein made mistakes. But good scientists speaking on their expertise have higher chance to be right than novices.

Wrong: It is scientific and so must be right.

Correct: It depends on who is the one calling it scientific. Good experts? Administrators? Reporters? Also, scientific results evolve with time and could be wrong in the future (when new evidences emerge, like in some medicine).
What to Communicate

Basic Messages
Basic Message 1: Everything Begins with Big Bang

The cosmic timeline continues with fairly well-established events leading to the present day.

Earliest Moments of the Big Bang → Formation of Atoms

- $10^{-35}$ second: Cosmic inflation creates a large, smooth patch of space filled with lumpy quark soup.
- $10^{-30}$ s: One potential type of dark matter (axions) is synthesized.
- $10^{-11}$ s: Matter gains the upper hand over antimatter.
- $10^{-10}$ s: A second potential type of dark matter (neutralinos) is synthesized.
- $10^{-5}$ s: Protons and neutrons form from quarks.
- 0.01–300 s: Helium, lithium, and heavy hydrogen nuclei form from protons and neutrons.
- 380,000 years: Atoms form from nuclei and electrons, releasing the cosmic microwave background radiation.

Dark Ages → Modern Era

- 380,000–300 million yr: Gravity continues to amplify density differences in the gas that fills space.
- 300 million yr: First stars and galaxies form.
- 1 billion yr: Limit of current observations (highest-redshift objects).
- 3 billion yr: Clusters of galaxies form; star formation peaks.
- 9 billion yr: Solar system forms.
- 10 billion yr: Dark energy takes hold and expansion begins to accelerate.
- 13.7 billion yr: Today

Everything on Earth is made of atoms (come chiefly from stars)!
Basic Message 2: We Are One Family

Our ancestor
Microbrachius
8 cm, 0.4 billion year ago

Family tree
Fish

Plato
Confucius
Laozi

Shakespeare

Obama
Fan Bingbing

You
me

Darwin’s evolutionary theory (1859)
Importance of humanities (*the disciplines*) could be seen:

1. If all present “science” research is stopped, the world is still the same—chaos and tragedies will continue—because it is the humanities (underdeveloped in the last 2600 years since Plato) that matters in human affairs.

2. Another way of seeing this is through the lesson of Apple company.

Putting a good humanist among “scientists”/engineers could create great companies—good for the economy.
What to Communicate

Uncertainty and Complex System
The human world is stochastic, i.e., probability is involved.

Non-deterministic system: has to ask different questions

Random Walk: An example

- The exact trajectory is different each time: can’t be predicted.
- But, e.g., average distance traveled is proportional to square root of time—can be predicted.

Louis Bachelier
PhD thesis in economics (1900)

Einstein
Brownian motion paper (1905)
Why eventually there always is a winner in Lotto?

Lotto first prize
→ one box will be hit
Winner is the one whose box is hit

Events with small probability, no matter how small, could actually happen.

Given: a (zero-size) raindrop will fall on this graph paper
p = probability that a box will be hit

\[ p = \frac{1}{84} = 0.012 \text{ (1.2\%)} \]
\[ p = \frac{1}{(84)^2} = 0.00014 \text{ (0.014\%)} \]

- Probability is an intrinsic part of the human world.
- We simply have to go on living with uncertainty, more *wisely* and *humbly*. 

Probability and Uncertainty
What it means to say the height of students in class $H$ is given by

$$H = 160 \pm 8 \text{ cm}$$

It does not mean $152 \leq H \leq 168 \text{ cm}$

Mean = 160 cm
Standard deviation (SD) = 8 cm
Steven Hawking:

“Complex systems is the most important science in the 21\textsuperscript{th} century.”

All human problems and the world around us are complex systems.

Predictions, when possible, are (mostly) probabilistic.

Only 15 years ago, complex systems science had to justify its existence. Today it is taking the world by storm. Networks, big data, cascading crises, extreme events, the word "systems," and many other ideas are widely accepted.
Climate Change: An Example

Observational data fit the trend of a combination of natural and human factors (rather than natural factors only).

That is, human factors are important.

Melillo et al, “Human and natural influences on climate” (2014)

- Climate is a complex system with **intrinsic** uncertainty.

- **No exact theory** (computer results only).

- Any prediction is probabilistic.

- Any decision about global warming is an educated gamble (because “black swan” outcomes could actually happen) and thus should be made by the whole human race ➔ science communication has important role to play.
What to Communicate 3

Science of Innovation
Innovation in Art

Realism

Expressionism

Modernism

Need no verification
Innovation in Business

Facebook

Fun

Discover vacuum

Fill the vacuum

Need “quick” verification
Science has two parts: Scientific process + Scientific results

... Innovation...

Human dependent

Produce breakthrough, original works

Scimat

Need verification

Innovation is a branch of scimat!

All human matters are probabilistic. Exceptions could and do occur!
Left brain controls language, logical thinking, rationality

Right brain controls innovation, imagination, sensuality

Mind: 10% conscious; 90% subconscious (→ innovation not come from smartness alone)

Innovation happening

- Stimulated by environment (usually at initial stage)
- Intense thinking + subconscious induced thought “jumping” (usually at middle stages)

Necessity of intermittent relaxation

Innovation not a purely deductive process (but involves left and right brains, rationality and sensuality)
Individual thinking better than collective thinking

Individuals more efficient than groups

Small groups better than large groups

Bonus is counterproductive

These unexpected results contradict our common sense.

Innovation process

• Janusian

• Sepcon

• Homospatial

Psychologists’ experimental results

**Flight from Wonder:** An Investigation of Scientific Creativity, A. Rothenberg (Oxford U P, 2015)

**The Creative Crisis:** Reinventing Science to Unleash Possibility, R. B. Ness (Oxford U P, 2015)

**How to Fly a Horse:** The Secret History of Creation, Invention, and Discovery, K. Ashton (Doubleday, 2015)
As organization

• Continue to support big science/national labs
• Prepare to support individuals
• Protect independent-minded, “strange” individuals
• Raise the basic salary of all scientists to upper middle level
• Don’t add trouble (don’t count papers; lower the threshold of scientific frauds)

As individual

• Control time usage (simplify life, don’t cook, rest suitably, write less papers…)
• Bulk the trend (don’t do hot topics unless you have a good idea)
• Don’t follow others (don’t use other’s method doing same problem unless…)
• Try more, have fun (follow your own interest, review failures)
• Physical strength (exercise, be healthy)

In China, innovation obstacles come from too many rules restricting attempted innovators, not because of insufficient funding.
Paper Counting and Innovation

Increasing publications

Irrelevant to innovation

Paper and wine

Cheering  Suitable number of papers

Drunk  Too many papers

Innovation impossible

Zombie  Fraud
1965 Nobel Prize in Physics
Quantum Electrodynamics

<table>
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<th>Year</th>
<th>Reference</th>
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In science communication (scicomm),

the essence of the so-called “scientific method” (such as the scientific spirit and scientific tradition) and the knowledge of human-related parts of science (concepts of uncertainty and probability, the humanities and social sciences) could be more important than those about non-living systems.

Popularizing complex systems will help the public to understand complex issues (e.g., global climate change) and be better, responsible citizens, and will make China the leader in the field of science communication.

Communicating the science of innovation will help China’s change in economical structure.
**Human Migration**

**Chinese ancestor**

Earliest known migration out of Africa
# Approaches in Ancient Philosophies

<table>
<thead>
<tr>
<th>Greece</th>
<th>China</th>
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</thead>
<tbody>
<tr>
<td>About anything</td>
<td>Mostly about social harmony/stability</td>
</tr>
<tr>
<td>Freedom of speech</td>
<td>Lack of freedom of speech</td>
</tr>
<tr>
<td>Supported by slavery</td>
<td>“Feudal” kingdoms</td>
</tr>
<tr>
<td>Analytic</td>
<td>Fuzzy/circular arguments  <em>(hu you, intentionally mislead)</em></td>
</tr>
<tr>
<td></td>
<td>Philosophers never wrote clearly or argued convincingly</td>
</tr>
<tr>
<td>Debate</td>
<td>No <em>(or not much)</em> debate</td>
</tr>
<tr>
<td>Socratic method</td>
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Ancient Greek philosophers didn’t need a regular job and lived in a democracy, and so were free in picking topics in pursuing acknowledge.

Ancient Greek philosophers cared about everything in daily life (and the Universe) and wanted to understand (analytically) and solve problems.

In ancient Greece, philosophy was the only discipline of learning which actually was very successful (all disciplines today branched out from it).
In ancient China, unlike in Greece, philosophy was not conducted analytically. They are more like Buddhist verses or “chicken soups” (called “Chinese wisdom” by others).

The philosophers, unlike the Greeks, never wrote clearly or argued convincingly.

When pressed, they will appeal to the will of Tian (“heaven”) or the good old ways of the (barely existent) ancient dynasties.

All, except Zhuangzi, concentrated in ethics/morality issues because that was the way to find a (government) job, unlike the ancient Greeks who didn’t need a job.

Mozi (not Confucius) is most relevant to China today.

Ancient Chinese philosophy is *huyouism* (忽悠主义), aiming to maintain social harmony/stability instead of finding out the “truth” or advancing knowledge.

But it is “useful” to a certain extent (the longest dynasty—Tang from AD 618–907, lasts 289 years).