The Thinker's Guide to

SCIENTIFIC THINKING

Based on Critical Thinking Concepts & Principles

FOURTH EDITION

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ROWMAN & LITTLEFIELD
Lanham • Boulder • New York • London

Why A Thinker's Guide to Scientific Thinking?

This guide is designed for students and faculty. It consists of the essence of scientific thinking concepts and tools. For faculty it provides a shared concept of scientific thinking. For students it is a scientific thinking supplement to any textbook for any science course. Faculty can use it to design science instruction, assignments, and tests. Students can use it to improve their perspective in any domain of science.

Generic scientific thinking skills apply to all sciences. For example, scientific thinkers are clear as to the purpose at hand and the question at issue. They question information, conclusions, and points of view. They strive to be accurate, precise, and relevant. They seek to think beneath the surface, to be logical and objective. They apply these skills to their reading and writing as well as to their speaking and listening. They apply them in professional and personal life.

When this guide is used as a supplement to the science textbook in multiple courses, students begin to perceive the application of scientific thinking to many domains in everyday life. And if their instructors provide examples of the application of scientific thinking to daily life, students begin to see scientific thinking as a tool for improving the quality of their lives.

If you are a student using this guide, get in the habit of carrying it with you to every science class. Consult it frequently in analyzing and synthesizing what you are learning. Aim for deep internalization of the principles you find in it—until using them becomes second nature.

If successful, this guide will serve faculty, students, and the science program simultaneously.

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Why Scientific Thinking?

The Problem:

Everyone thinks; it is our nature to do so. But much of our thinking, left to itself, is biased, distorted, partial, uninformed, or down-right prejudiced. Yet the quality of our life and that of what we produce, make, or build depends precisely on the quality of our thought. Shoddy thinking is costly, both in money and in quality of life. Excellence in thought, however, must be systematically cultivated.

A Definition:

Scientific thinking is that mode of thinking in which the thinker improves the quality of his or her thinking — about any scientific subject, content, or problem — by skillfully taking charge of the structures inherent in thinking and imposing intellectual standards upon them.

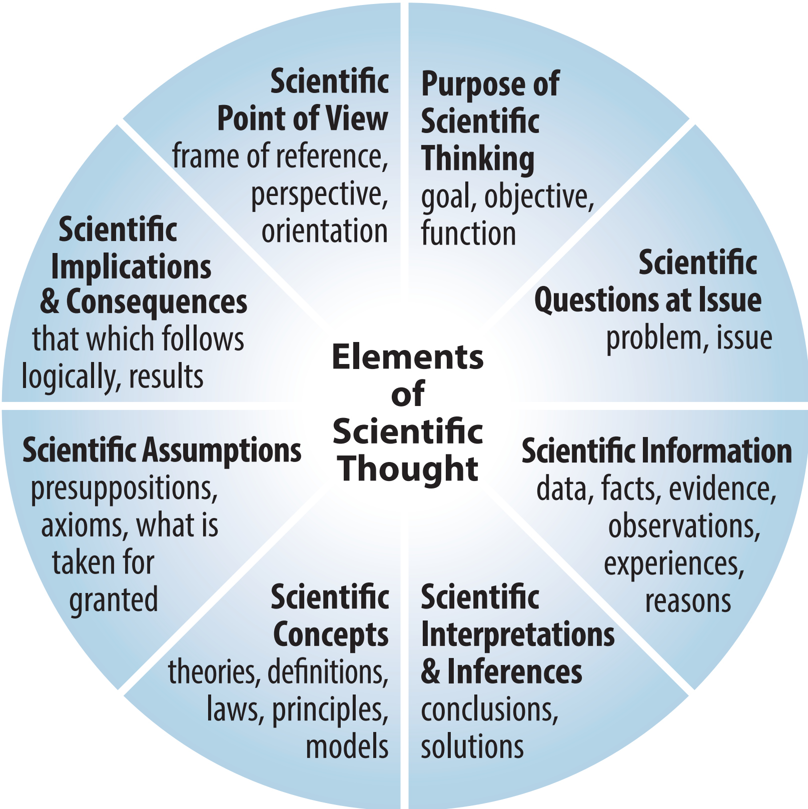
The Result:

A well-cultivated scientific thinker:

- raises vital scientific questions and problems, formulating them clearly and precisely;
- gathers and assesses relevant scientific data and information, using scientific laws, theories, and ideas to interpret them effectively;
- comes to well-reasoned scientific conclusions and solutions, testing them against relevant criteria and standards;
- thinks open-mindedly within convergent systems of scientific thought, recognizing and assessing scientific assumptions, implications, and practical consequences; and
- communicates effectively with others in proposing solutions to complex scientific problems.

Scientific thinking is, like all critical thinking, self-directed, self-disciplined, self-monitored, and self-corrective. It presupposes assent to rigorous standards of excellence and mindful command of their use. It entails effective communication and problem-solving abilities, as well as a commitment to developing the intellectual skills, abilities, and dispositions of the critical mind.

The Elements of Scientific Thought



Used With Sensitivity to Universal Intellectual Standards

Clarity → Accuracy → Depth → Breadth → Significance
Precision ↓
Relevance Fairness

Scientific Thinking Seeks to Quantify, Explain, and Predict Relationships in Nature

> The true scientific investigator never jumps at conclusions, never takes anything for granted, never considers his judgment better than his information, and never substitutes opinions or long established belief for fact. No matter how plausible a given statement may be or how logical a proposed explanation of it may seem, it must be treated merely as a supposition until it has been proved true by searching tests. Moreover, these tests must be of such kind that other scientists can repeat them, and of such nature that others repeating them will inevitably come to the same conclusions. Only in this manner can a body of dependable scientific knowledge be built up.
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> *Lincoln Library of Essential Information, 1940*

Scientific thinking is based on a belief in the intelligibility of nature, that is, upon the belief that the same cause operating under the same conditions will result in the same effects at any time. As a result of this belief, scientists pursue the following goals.

1. **They Observe. (What conditions seem to affect the phenomena we are observing?)** In order to determine the causal relations of physical occurrences or phenomena, scientists seek to identify factors that affect what they are studying.
2. **They Design Experiments. (When we isolate potential causal factors, which seem to most directly cause the phenomena, and which do not?)** In scientific experiments, the experimenter sets up the experiment so as to maintain control over all likely causal factors being examined. Experimenters then isolate each variable and observe its effect on the phenomena being studied to determine which factors are essential to the causal effect.
3. **They Strive for Exact Measurement. (What are the precise quantitative relationships between essential factors and their effects?)** Scientists seek to determine the exact quantitative relationships between essential factors and resulting effects.
4. **They Seek to Formulate Physical Laws. (Can we state the precise quantitative relationship in the form of a law?)** The quantitative cause-effect relationship, with its limitations clearly specified, is known as a physical law. For example, it is found that for a constant mass of gas, at a constant

Analyzing & Assessing Scientific Research

Use this template to assess the quality of any scientific research project or paper.

1) All scientific research has a fundamental PURPOSE and goal.
   - Clearly state research purposes and goals.
   - Related purposes should be explicitly distinguished.
   - All segments of the research should be relevant to the purpose.
   - All research purposes should be realistic and significant.

2) All scientific research addresses a fundamental QUESTION, problem or issue.
   - Clearly and precisely state the fundamental question at issue.
   - Related questions should be articulated and distinguished.
   - All segments of the research should be relevant to the central question.
   - All research questions should be realistic and significant.
   - All research questions should define clearly stated intellectual tasks that, being fulfilled, settle the questions.

3) All scientific research identifies data, INFORMATION, and evidence relevant to its fundamental question and purpose.
   - All information used should be clear, accurate, and relevant to the fundamental question at issue.
   - Information gathered must be sufficient to settle, or significantly contribute to the settling of, the question at issue.
   - Information contrary to the main conclusions of the research should be explained.

4) All scientific research contains INFERENCES or interpretations by which conclusions are drawn.
   - All conclusions should be clear, accurate, and relevant to the key question at issue.
   - Conclusions drawn should not go beyond what the data imply.
   - Conclusions should be consistent and reconcile, or at least attempt to reconcile, discrepancies in the data.
   - Conclusions should explain how the key questions at issue have been settled.

The Logic of Physics

The Goal of Physics is to discover the physical forces, interactions, and properties of matter, including the physical properties of the atom and sub-atomic particles. In pursuing this end, physicists study gravitation, motion, space, time, force, and energy. This entails the study of mechanics, heat, light, sound, electricity, magnetism, and the constitution of matter. Physics conducts its study of the physical properties of matter and energy insofar as these properties can be measured, expressed in mathematical formulas, and explained by physical theories. Its goals may be contrasted with those of chemistry (which focuses on chemical properties, on the composition and transformations of matter) and those of biology (which focuses on living matter).

Its Key Question is: What are the physical properties of matter and energy insofar as both can be measured, expressed in mathematical formulas, and explained by physical theories? (Physical properties can change without changing the identity of the matter; chemical properties cannot change without changing the identity of the matter.)

Its Key Concepts include: Matter, energy, mass, space, time, light, work, entropy, motion, volume, density, weight, magnitude, direction, displacement, velocity, acceleration, momentum, inertia, equilibrium, friction, gravitation, mechanics, heat, sound, electricity, magnetism, chaos theory, quantum, and relativity.

Its Key Assumptions are: That the universe is controlled by laws, that the same laws apply throughout the universe, that the laws guiding the universe can be expressed in mathematical terms and formulas, that physical properties can be distinguished from chemical ones, that the velocity of light is constant throughout, that space and time are interrelated, that all motion is relative, and that the forces of inertia, gravitation, and electromagnetism are different manifestations of a single force.

The Data or Information Physicists Gather are all focused on the causal relations or statistical correlations of physical occurrences or phenomena. Physicists use information from many physical sources such as heat, light, sound, mechanics, electricity, and magnetism to come to conclusions about the physical world. They study atoms, particles, neutrons, and electrons. They observe the ways in which moving bodies behave and stationary bodies react to pressure and other forces. They observe waves and small particles. They observe how physical forces affect living things. In short, the physical world provides a virtually unlimited store of data for the various types of physicists to observe.

Inferences, Generalizations, or Hypotheses are made regarding the scope of the phenomena. When possible, physicists seek general hypotheses or physical theories that they can test, modify, and perfect by extended study and experimentation. When successful, they predict new physical phenomena in line with a given theory and then conduct further observations or experiments to confirm or falsify them.

Implications. The huge growth in knowledge and understanding of the physical world, as a result of advances in physics, carries with it important implications for quality of life in many dimensions of human existence. It has provided the foundations of engineering. It enables us to build power plants, trucks, airplanes, trains, televisions, and telephones. Most machinery and tools, for example, are dependent on knowledge of physics. Most construction of buildings, irrigation and sewer systems, solar power alternatives, and the instrumentation of modern medicine are products of modern physics. Our knowledge of physics has also (arguably) been misused in the building of weapons of mass destruction, in our polluting of the environment, and in our use of mechanisms by which to invade the privacy of citizens.

The Point of View: Physicists see the universe, as well as the physical world and everything in it, as ultimately explainable and understandable through physical theories and laws. Many physicists see the universe as open to almost unlimited exploration and discovery.