

*"Nothing in life is to be feared, it is only to be understood.  
Now is the time to understand more, so that we may fear less."*

— MARIE CURIE

# THE THINKER'S GUIDE TO SCIENTIFIC THINKING



*Pierre and Marie Curie*

Based on Critical Thinking  
Concepts & Principles

By DR. RICHARD PAUL and DR. LINDA ELDER

THINKER'S GUIDE LIBRARY



## 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.



Richard Paul  
Center for Critical Thinking



Linda Elder  
Foundation for Critical Thinking

# Contents

Why Scientific Thinking? ..... 3

The Elements of Scientific Thought ..... 4

Questions Using the Elements of Scientific Thought ..... 5

A Checklist for Scientific Reasoning ..... 6

Scientific Thinking Seeks to Quantify, Explain,  
and Predict Relationships in Nature ..... 8

Universal Intellectual Standards Essential to Sound Scientific Thinking ..... 10

Intellectual Standards in Scientific Thinking ..... 12

The Figuring Mind Thinking Scientifically ..... 13

How to Analyze the Logic of a Scientific Article, Essay, or Chapter ..... 14

Analyzing the Logic of a Science Textbook ..... 16

The Logic of a Science Textbook ..... 16

Experimental Thinking Requires Experimental Controls ..... 17

The Logic of an Experiment ..... 18

Post Experiment Analysis ..... 19

How to Evaluate an Author's or Experimenter's Scientific Reasoning ..... 20

Two Kinds of Scientific Questions ..... 21

Asking One System and Conflicting System Questions ..... 22

Scientific Reasoning Abilities ..... 24

Analyzing & Assessing Scientific Research ..... 25

Purpose ..... 26

Questions at Issue or Central Problem ..... 27

Information ..... 28

Inference and Interpretation ..... 29

Assumptions ..... 30

Concepts and Ideas ..... 31

Point of View ..... 32

Implications and Consequences . . . . .	33
Intellectual Dispositions Essential to Scientific Thinking . . . . .	34
Scientific Thinkers Routinely Apply the Intellectual Standards. . . . .	36
Development of the Scientific Mind . . . . .	37
Analyzing the Logic of a Subject. . . . .	38
The Logic of Scientific Reasoning . . . . .	39
The Questioning Mind in Science. . . . .	40
The Logic of Science . . . . .	42
The Logic of Physics . . . . .	43
The Logic of Chemistry . . . . .	44
The Logic of Geology . . . . .	45
The Logic of Astronomy. . . . .	46
The Logic of Biology . . . . .	47
The Logic of Zoology . . . . .	48
The Logic of Botany. . . . .	49
The Logic of Biochemistry. . . . .	50
The Logic of Paleontology. . . . .	51
The Logic of Animal Physiology . . . . .	52
The Logic of Archaeology . . . . .	53
The Logic of Ecology . . . . .	54
The Problem of Pseudo-Scientific and Unscientific Thinking . . . . .	55
A Pseudo-Science: Why Astrology Is Not a Science . . . . .	56
A Critical Approach to Scientific Thinking . . . . .	59
Ethics and Science . . . . .	61

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

## The Result:

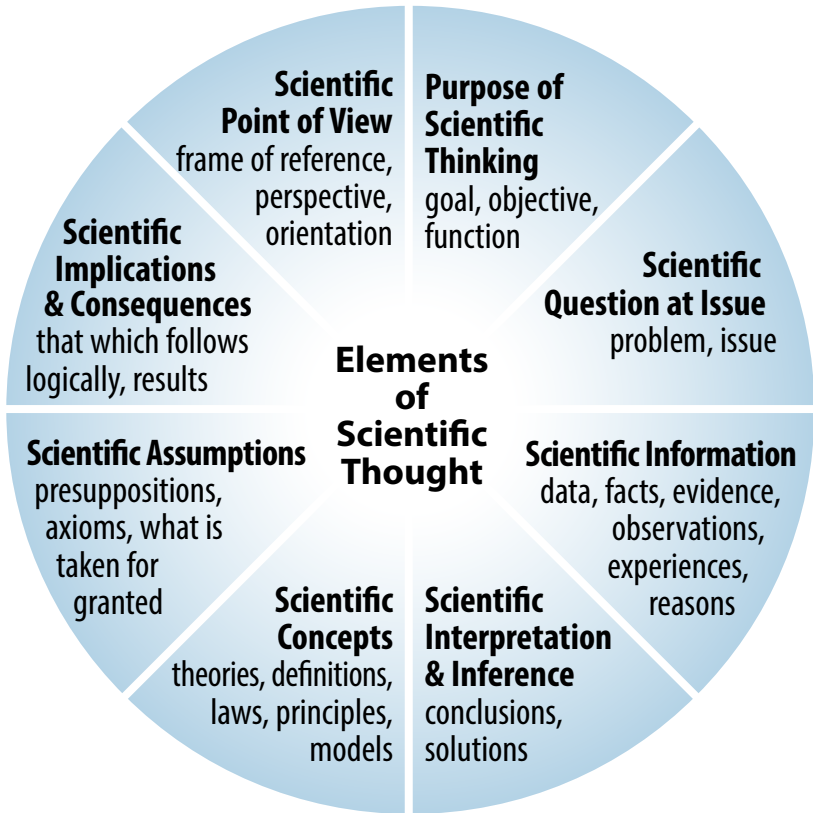
A well cultivated scientific thinker:

- raises vital scientific questions and problems, formulating them clearly and precisely;
- gathers and assesses relevant scientific data and information, using abstract ideas to interpret them effectively;
- comes to well-reasoned scientific conclusions and solutions, testing them against relevant criteria and standards;
- thinks openmindedly 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, in short, 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 scientific skills, abilities, and dispositions.

# The Elements of Scientific Thought



## Used With Sensitivity to Universal Intellectual Standards

Clarity → Accuracy → Depth → Breadth → Significance  
 Precision  
 Relevance

↓  
Fairness

## A Checklist for Scientific Reasoning

### 1) All scientific reasoning has a **PURPOSE**.

- Take time to state your purpose clearly.
- Distinguish your purpose from related purposes.
- Check periodically to be sure you are still on target.
- Choose significant and realistic scientific purposes.

### 2) All reasoning is an attempt to figure something out, to settle some scientific **QUESTION**, to solve some scientific **PROBLEM**.

- State the question at issue clearly and precisely.
- Express the question in several ways to clarify its meaning and scope.
- Break the question into sub-questions.
- Distinguish questions that have definitive answers from those that are a matter of opinion and from those that require consideration of multiple viewpoints.

### 3) All scientific reasoning is based on **ASSUMPTIONS**.

- Clearly identify your assumptions and determine whether they are justifiable.
- Consider how your assumptions are shaping your point of view.

### 4) All scientific reasoning is done from some **POINT OF VIEW**.

- Identify your point of view.
- Seek other points of view and identify their strengths as well as weaknesses.
- Strive to be fairminded in evaluating all scientific points of view.

**5) All scientific reasoning is based on DATA, INFORMATION and EVIDENCE.**

- Restrict your claims to those supported by the available data.
- Search for information that opposes your position as well as information that supports it.
- Make sure that all information used is clear, accurate and relevant to the question at issue.
- Make sure you have gathered sufficient information.

**6) All scientific reasoning is expressed through, and shaped by, scientific CONCEPTS and IDEAS.**

- Identify key scientific concepts and explain them clearly.
- Consider alternative concepts or alternative definitions of concepts.
- Make sure you use concepts with precision.

**7) All scientific reasoning entails INFERENCES or INTERPRETATIONS by which we draw scientific CONCLUSIONS and give meaning to scientific data.**

- Infer only what the evidence implies.
- Check inferences for their consistency with each other.
- Identify assumptions underlying your inferences.

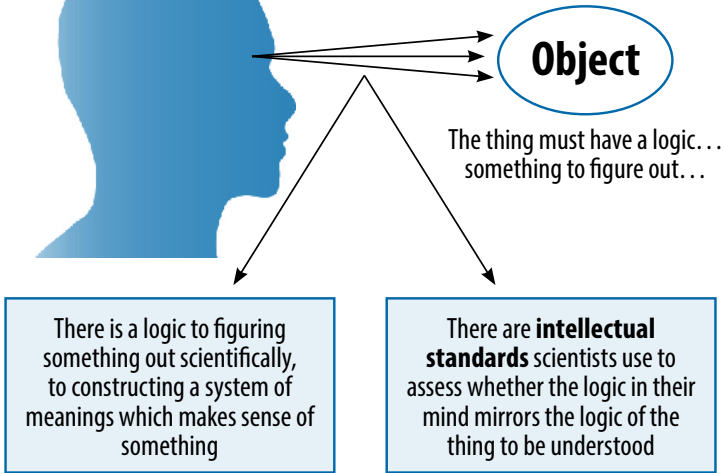
**8) All scientific reasoning leads somewhere or has IMPLICATIONS and CONSEQUENCES.**

- Trace the implications and consequences that follow from your reasoning.
- Search for negative as well as positive implications.
- Consider all possible consequences.



# The Figuring Mind

*Thinking Scientifically*



The Elements of Thought reveal the logic:		Intellectual Standards include:	
1	An object to be figured out		some data or information, some experience of it (the <b>Empirical Dimension</b> )
2	Some reason for wanting to figure it out		our <b>Purpose</b> or <b>Goal</b>
3	Some question or problem we want solved		our <b>Question at Issue</b>
4	Some initial sense of the object (whatever we take for granted)		our <b>Assumptions</b>
5	Some ideas by which we are making sense of the object		the <b>Conceptual Dimension</b>
6	Some drawing of conclusions about the object		our <b>Inferences</b> or interpretations
7	What follows from our interpretation of the object		the <b>Implications</b> and <b>Consequences</b>
8	Some viewpoint from which we conceptualize the object		our <b>Point of View</b> or <b>Frame of Reference</b>

## Experimental Thinking Requires Experimental Controls

To maintain control over all likely casual factors being examined, experimenters isolate each variable and observe its effects on the phenomena being studied to determine which factors are essential to the causal effects.

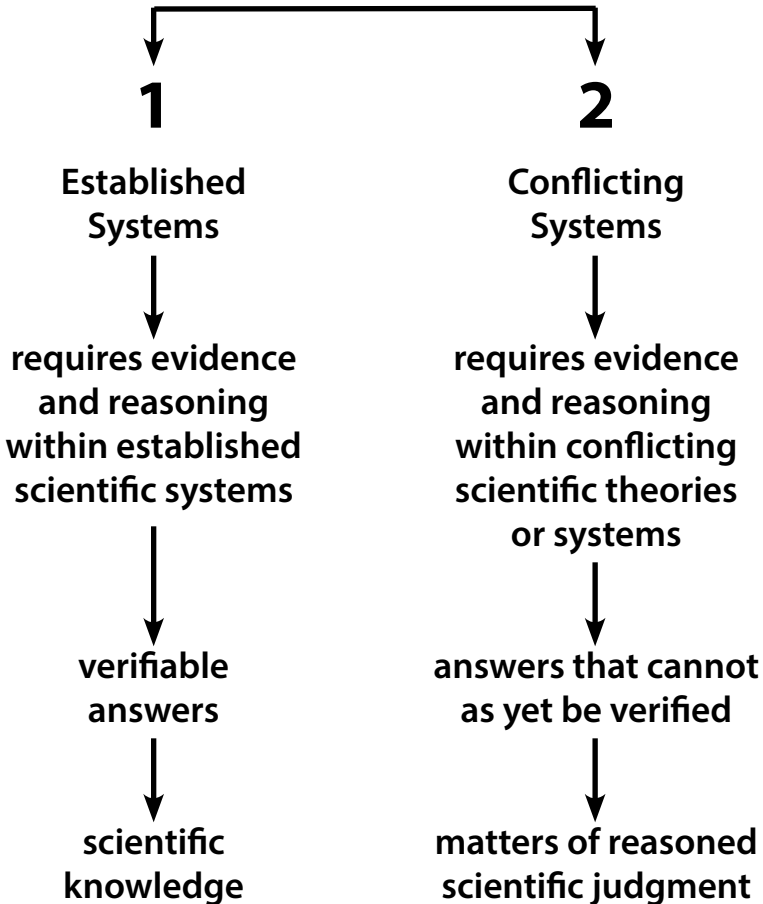
**Experiments Can Go Awry When Scientists Fail to Control for Confounded Variables.** Often, a range of variables are 'associated' with a given effect, while only one of the variables is truly responsible for the effect. For example, it has been found that in France, where people drink a lot of red wine, the incidence of heart attacks is lower than in countries of northern Europe where red wine is less popular. Can we conclude from this statistical study that the regular drinking of moderate amounts of red wine can prevent the occurrence of heart attacks? No, because there are many other differences between the life styles of people in France and those in northern Europe, for example diet, work habits, climate, smoking, commuting, air pollution, inherited pre-dispositions, etc. These other variables are 'associated' or 'confounded' with the red wine variable. One or more of these confounded variables might be the actual cause of the low incidence of heart attacks in France. These variables would have to be controlled in some way before one could conclude that drinking red wine lowers the incidence of heart attacks.

A possible experimental design would be to compare Frenchmen who drink red wine with those who drink no alcohol at all or drink beer — making sure that these groups do not differ on any other measurable variables. Or we might study northern Europeans who drink red wine and see if the incidence of heart attack is lower among them than among northern Europeans who do not drink red wine. We could also take a group of patients who have had a heart attack, and instruct one half to drink a little red wine every day, and tell the other group to drink apple juice. After a number of years we could compare the rate of incidence of heart attacks in the two groups.



## Two Kinds of Scientific Questions

In approaching a question, it is useful to figure out what type it is. Is it a question with one definitive answer? Or does the question require us to consider competing points of view?



See explications and examples of both types of questions on the following two pages.

## Purpose

(All scientific reasoning has a purpose.)

**Primary Standards:** (1) Clarity, (2) Significance, (3) Achievability  
(4) Consistency, (5) Justifiability

**Common Problems:** (1) Unclear, (2) Trivial, (3) Unrealistic, (4) Contradictory,  
(5) Unfair

**Principle:** To reason well, you must clearly understand your purpose, and your purpose must be reasonable and fair.

Skilled Thinkers...	Unskilled Thinkers...	Critical Reflections
Take the time to state their purpose clearly.	Are often unclear about their central purpose.	Have I made the purpose of my reasoning clear? What exactly am I trying to achieve? Have I stated the purpose in several ways to clarify it?
Distinguish it from related purposes.	Oscillate between different, sometimes contradictory purposes.	What different purposes do I have in mind? How do I see them as related? Am I going off in somewhat different directions? How can I reconcile these contradictory purposes?
Periodically remind themselves of their purpose to determine whether they are straying from it.	Lose track of their fundamental object or goal	In writing this proposal, do I seem to be wandering from my purpose? How do my third and fourth paragraph relate to my central goal?
Adopt realistic purposes and goals.	Adopt unrealistic purposes and set unrealistic goals.	Am I trying to accomplish too much in this project?
Choose significant purposes and goals.	Adopt trivial purposes and goals as if they were significant.	What is the significance of pursuing this particular purpose? Is there a more significant purpose I should be focused on?
Choose goals and purposes that are consistent with other goals and purposes they have chosen.	Inadvertently negate their own purposes. Do not monitor their thinking for inconsistent goals.	Does one part of my proposal seem to undermine what I am trying to accomplish in another part?
Adjust their thinking regularly to their purpose.	Do not adjust their thinking regularly to their purpose.	Does my argument stick to the issue? Am I acting consistently within my purpose?
Choose purposes that are fair-minded, considering the desires and rights of others equally with their own desires and rights.	Choose purposes that are self-serving at the expense of others' needs and desires.	Is my purpose self-serving or concerned only with my own desires? Does it take into account the rights and needs of other people?

The Foundation for Critical Thinking  
PO Box 196  
Tombales, CA 94971



## About the Authors



Dr. Linda Elder is an education psychologist who has taught both psychology and critical thinking at the college level. She is the President of the Foundation for Critical Thinking and the Executive Director of the Center for Critical Thinking. Dr. Elder has a special interest in the relation of thought and emotion, the cognitive and the affective, and has developed an original theory of the stages of critical thinking development. She has coauthored four books on critical thinking, as well as twenty-one thinkers' guides.



Dr. Richard Paul is a major leader in the international critical thinking movement. He is Director of Research at the Center for Critical Thinking, and the Chair of the National Council for Excellence in Critical Thinking, author of over 200 articles and seven books on critical thinking. Dr. Paul has given hundreds of workshops on critical thinking and made a series of eight critical thinking video programs for P.B.S. His views on critical thinking have been canvassed in *The New York Times*, *Education Week*, *The Chronicle of Higher Education*, *American Teacher*, *Educational Leadership*, *Newsweek*, *U.S. News & World Report*, and *Reader's Digest*.

ISBN 978-0-944583-18-0 Item #590m

THINKER'S GUIDE LIBRARY

