RICHARD PAUL AND LINDA ELDER

FOURTH EDITION

The Thinker's Guide to SCIENTIFIC THINKING

Based on Critical Thinking Concepts and Principles

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The Thinker's Guide to

Based on Critical Thinking
Concepts & Principles

FOURTH EDITION

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Contents

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 → Fairness

Precision

Relevance

Questions Using the Elements of Scientific Thought

(in a scientific paper)

A Checklist for Scientific Reasoning

1) All scientific reasoning has a PURPOSE.

- Can you state your scientific purpose clearly?
- Can you distinguish your purpose from related purposes?
- Have you checked periodically to be sure you are still on target?
- Have you chosen 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.

- Can you state the scientific question at issue clearly and precisely?
- Can you express the question in several ways to clarify its meaning and scope?
- Can you break the question into sub-questions?
- Can you distinguish scientific 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.

- Can you clearly identify the assumptions you are using when coming to scientific conclusions? Are these assumptions justifiable?
- Have you considered how your assumptions are shaping your scientific point of view?

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

- Can you identify your point of view?
- Can you seek other points of view and identify their strengths as well as weaknesses?
- Can you strive to be fairminded in evaluating all scientific points of view?

temperature, the volume is inversely related to the pressure applied to it; in other words, the greater the pressure the less the volume — the greater the volume the less the pressure. This relationship is constant for most gases within a moderate range of pressure. This relationship is known as *Boyle's Law*. It is a physical **law** because it *defines* a cause-effect relationship, but it does not *explain* the relationship.

5. **They Study Related or Similar Phenomena.** (When we examine many related or similar phenomena, can we make a generalization that covers them all?) A study of many related or similar phenomena is typically carried out to determine whether a generalization or hypothesis can be formulated that accounts for, or explains, them all.

6. **They Seek to Test, Modify, and Refine Hypotheses.** If a generalization is formulated, scientists test, modify, and refine it through comprehensive study and experimentation, extending it to all known phenomena to which it may have any relation, restricting its use where necessary, or broadening its use in suggesting and predicting new phenomena.

7. **When Possible, Scientists Seek to Establish General Physical Laws as well as Comprehensive Physical Theories.** General physical laws and comprehensive physical theories are broadly applicable in predicting and explaining the physical world. The *Law of Gravitation*, for example, is a general physical law. It states that every portion of matter attracts every other portion with a force directly proportional to the product of the two masses, and inversely proportional to the square of the distance between the two. Darwin's *Theory of Evolution* according to natural selection is a comprehensive physical theory. It hol
and animals
forms by her
slight variatio
generations,
determines w

Universal Intellectual Standards Essential to Sound Scientific Thinking

Universal intellectual standards are standards which must be applied to thinking whenever one is interested in checking the quality of reasoning about a problem, issue, or situation. To think scientifically entails having command of these standards. While there are many universal standards[1], we focus here on some of the most significant:

Clarity:

Could you elaborate further on that point? Could you express that point in another way? Could you give me an illustration? Could you give me an example?

Clarity is a gateway standard. If a statement is unclear, we cannot determine whether it is accurate or relevant. In fact, we cannot tell anything about it because we don't yet know what it is saying.

Accuracy:

Is that really true? How could we check that? How could we find out if that is true?

A statement can be clear but not accurate, as in the following statements: "Humans make use of only 10% of their brains." "The stress of modern life plays a significant role in causing stomach ulcers." "Animal behavior allows us to predict earthquakes with high degree of probability." "Cold fusion—nuclear fusion that takes place at temperatures lower than millions of degrees—is a potential source of inexpensive energy."

Precision:

Could you give me more details? Could you be more specific?

A statement can be both clear and accurate, but not precise, as in "The solution in the beaker is hot." (We don't know how hot it is.)

Relevance:

How is that connected to the question? How does that bear on the issue? A statement can be clear, accurate, and precise, but not relevant to the question at issue.

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[1] There are hundreds or more intellectual standards extant in natural languages (the languages we speak every day). For more on intellectual standards, see *The Thinker's Guide to Intellectual Standards* by Linda Elder and Richard Paul (Dillion Beach: Foundation for Critical Thinking, 2008).

If a person who believed in astrology defended his/her view by saying "Many intelligent people believe in astrology," their defense would be clear, accurate, and sufficiently precise, but irrelevant. (For example, at one time many intelligent people believed the earth was flat.)

Depth:

How does your answer address the complexities in the question? How are you taking into account the problems in the question? Are you dealing with the most significant factors?

A statement can be clear, accurate, precise, and relevant, but superficial (that is, lack depth). Many scientific questions contain great complexity. For example, "How can we effectively reduce greenhouse gases and global warming?" This is a question that intrinsically entails addressing multiple approaches and focusing on a number of complex, interrelated issues, on their relationships, and on their consequences.

Breadth:

Do we need to consider another point of view? Is there another way to look at this question? What would this look like from the point of view of a conflicting theory, hypothesis or conceptual scheme?

A line of reasoning may be clear, accurate, precise, relevant, and deep, but lack breadth (as in an argument from either of two conflicting theories, both consistent with available evidence).

Logic:

Does this really make sense? Does that follow from what you said? How does that follow? Before you implied this and now you are saying that? I don't see how both can be true.

When we think, we bring a variety of thoughts together into some order. When the combination of thoughts are mutually supporting and make sense in combination, the thinking is "logical." When the combination is not mutually supporting, is contradictory in some sense, or does not "make sense," the combination is "not logical." For example, the attempt to predict earthquakes based on radon gases or animal behavior does not make sense in combination with our best geophysical theories. In scientific thinking, new conceptual schemes become working hypotheses when we deduce from them logical consequences which can be tested by experiment. If many of such consequences are shown to be true, the theory (hypothesis) which implied them may itself be accepted as true.

Intellectual Standards in Scientific Thinking

Understandable, the meaning can be grasped

Could you elaborate further on our hypothesis (or idea)? Could you give me a more detailed explanation of the phenomenon you have in mind?

Free from errors or distortions, true

How could we check on the data?
How could we verify or test our hypothesis?

Exact to the necessary level of detail

Could you be more specific? Could you give me more details on the phenomenon? Could you be more exact as to how the mechanism takes place?

Relating to the matter at hand

How does the scientific data relate to the problem? How do our findings bear on the question?

Containing complexities and multiple interrelationships

What factors make this a difficult scientific problem? What are some of the complexities we must consider? Are there dimensions to the problem that lie outside the realm of science that must be considered?

Encompassing multiple viewpoints

Do we need to look at this from another perspective? Do we need to consider another point of view? Do we need to look at this in other ways?

The parts make sense together, no contradictions

Are all the data consistent with each other? Are these two theories consistent? Is that implied by the data we have?

Focusing on the important, not trivial

Is this the central idea to focus on? Which set of data is most important?

Justifiable, not self-serving or one-sided

Do I have any vested interest in this issue which keeps me from looking at it objectively? Am I misrepresenting a view with which I disagree?

The Figuring Mind

Analyzing the Logic of a Science Textbook

Just as you can understand a scientific essay, article, or chapter by analyzing the parts of the author's reasoning, so can you figure out the system of ideas within a scientific textbook by focusing on the parts of the author's reasoning within the textbook. To understand the parts of the textbook author's reasoning, use this template:

The Logic of a Science Textbook

1) The main **purpose** of this textbook is ______________________________.

2) The key **question**(s) that the author is addressing in the textbook is(are)_ ____.

3) The most important kinds of **information** in this textbook are _________ ____.

4) The main **inferences** (and conclusions) in this textbook are ___________ ____.

5) The key **concept**(s) we need to understand in this textbook is(are) ______ ____.

   By these concepts the author means ______________________________ ____.

6) The main **assumption**(s) underlying the author's thinking is(are) ______ ____.

7a) If people take the textbook seriously, the **implications** are ____________ ____.

7b) If people fail to take the textbook seriously, the **implications** are _______ ____.

8) The main **point(s) of view** presented in this textbook is(are)___________ ____.

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 lower 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 significant 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.

The Logic of an Experiment

(Attach a detailed description of the experiment or laboratory procedure.)

The main goal of the experiment is ______________________________________

____.

The hypothesis(es) we seek to test in this experiment is(are) _______________

____

____.

The key question the experiment seeks to answer is _______________________

____.

The controls involved in this experiment are ____________________________

____.

The key concept(s) or theory(ies) behind the experiment is(are) _____________

____

____.

The experiment is based on the following assumptions____________________

____

____.

The data that will be collected in the experiment are_______________________

____

____.

The potential implications of the experiment are __________________________

____.

The point of view behind the experiment is ______________________________

____.

Post Experiment Analysis

The data collected during the experiment was ______________________________

____

____

____

____.

The inferences (conclusions) that most logically follow from the data are ______

____

____

____.

These inferences are/are not debatable, given the data gathered in this study and the evidence to this point.

The hypothesis (or hypotheses) for this experiment was/was not (were/were not) supported by the experiment results.

The assumptions made prior to this experiment should/should not be modified, given the data gathered in this experiment. Modifications to assumptions (if any) should be as follows ____

____

____

____.

The most significant implications of this experiment are______________________

____

____

____.

Recommendations for future research in this area are________________________

____

____

____.

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

1. Focusing on the stated scientific **Purpose:** Is the purpose of the author well-stated or clearly implied? Is it justifiable?
2. Focusing on the key scientific **Question:** Is the question at issue well-stated (or clearly implied)? Is it clear and unbiased? Does the expression of the question do justice to the complexity of the matter at issue? Are the question and purpose directly relevant to each other?
3. Focusing on the most important scientific **Information** or data: Does the writer cite relevant evidence, experiences, and/or information essential to the issue? Is the information accurate and directly relevant to the question at issue? Does the writer address the complexities of the issue? Does the experimenter clearly delineate the scientific data to be collected?
4. Focusing on the most fundamental **Concepts** at the heart of the scientific reasoning: Are the key ideas clarified? Are the ideas used justifiably? Does the experimenter clarify the theories behind the experiment?
5. Focusing on **Assumptions:** Does the scientific reasoner clearly delineate the scientific assumptions? Does s/he show a sensitivity to what s/he is taking for granted or assuming (insofar as those assumptions might reasonably be questioned)? Or does the reasoner use questionable assumptions without addressing problems inherent in those assumptions?
6. Focusing on the most important scientific **Inferences**, conclusions, or interpretations: Do the inferences and conclusions made by the scientific reasoner clearly follow from the information relevant to the issue, or does the reasoner jump to unjustifiable conclusions? Does the reasoner consider alternative interpretations or inferences where the scientific issue is complex? In other words, does the reasoner use a sound line of reasoning to come to logical scientific conclusions, or can you identify flaws in the reasoning somewhere? Does the experimenter clearly separate data from conclusions?
7. Focusing on the scientific **Point of View:** Does the reasoner show a sensitivity to alternative relevant scientific points of view or lines of reasoning? Does s/he consider and respond to objections framed from other relevant points of view?
8. Focusing on **Implications:** Does the reasoner display a sensitivity to the implications and consequences of the position s/he is taking?