



A Miniature Guide

For Students and Faculty

To

Scientific Thinking

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Based on
Critical Thinking Concepts & Principles

The Foundation for Critical Thinking

Why A Mini-Guide to Scientific Thinking?

This miniature guide is designed for administrators, faculty, and students. 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.

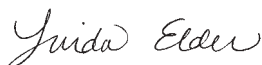
When this guide is used as a supplement to the science textbook in multiple courses, students begin to perceive the application of scientific thinking to many domains in everyday life. And if their instructors provide examples of the application of scientific thinking to daily life, students begin to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

If you are a student using this mini-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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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 realistic scientific purposes.

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

- Take time to clearly and precisely state the question at issue.
- Express the question in several ways to clarify its meaning and scope.
- Break the question into sub-questions.
- Determine if the question has one right answer, or requires reasoning from more than one hypothesis or point of view.

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. Make sure it is scientific.
- Seek other scientific points of view and identify their strengths as well as weaknesses.

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

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

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

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

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

- Infer only what the data implies.
- Check inferences for their consistency with each other.
- Identify assumptions which led you to your conclusions.

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

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

Intellectual Standards in Scientific Thinking

Clarity

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

Accuracy

How could we check on those data?
How could we verify or test that theory?

Precision

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?

Relevance

How do those data relate to the problem?
How do they bear on the question?

Depth

What factors make this a difficult scientific problem?
What are some of the complexities we must consider?

Breadth

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?

Logic

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

Significance

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

Fairness

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

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 _____

The Logic of Science

Goals Scientists Pursue: Scientists seek to figure out how the physical world operates through systematic observation, experimentation, and analysis. By analyzing the physical world, they seek to formulate principles, laws, and theories useful in explaining natural phenomena, and in guiding further scientific study.

Questions Scientists Ask: How does the physical world operate? What are the best methods for figuring things out about the physical world? What are the barriers to figuring things out about the physical world? How can we overcome those barriers?

Information Scientists Use: Scientists as a whole use virtually any type of information that can be gathered systematically through observation and measurement, though most specialize in analyzing specific kinds of information. To name just some of the information scientists use, they observe and examine plants, animals, planets, stars, rocks, rock formations, minerals, bodies of water, fossils, chemicals, phenomena in the earth's atmosphere and cells. They also observe interactions between phenomena.

Judgments Scientists Make: Scientists make judgments about the physical world based on observations and experimentation. These judgments lead to systematized knowledge, theories, and principles helpful in explaining and understanding the world.

Concepts that Guide Scientists' Thinking: The most fundamental concepts that guide the thinking of scientists are 1) *physical world* (of nature and all matter); 2) *hypothesis* (an unproved theory, proposition, or supposition tentatively accepted to explain certain facts or to provide a basis for further investigation); 3) *experimentation* (a systematic and operationalized process designed to figure out something about the physical world); and 4) *systematic observation* (the act or practice of noting or recording facts or events in the physical world). Other fundamental concepts in science include: theory, law, scientific method, pure sciences, and applied sciences.

Key Assumptions Scientists Make: 1) There are laws at work in the physical world that can be figured out through systematic observation and experimentation; 2) Much about the physical world is still unknown; 3) Through science, the quality of life on earth can be enhanced.

Implications of Science: Many important implications and consequences have resulted from scientific thinking, some of which have vastly improved the quality of life on earth, others of which have resulted in decreased quality of life (e.g., the destruction of the earth's forests, oceans, natural habitats, etc.). One important positive implication of scientific thinking is that it enables us to replace mythological thinking with theories and principles based in scientific fact.

The Scientific Point of View: Scientists look at the physical world and see phenomena best understood through careful observation and systematic study. They see scientific study as vital to understanding the physical world and replacing myth with scientific knowledge.

The Logic of Chemistry

The Goal of Chemistry is to study the most basic elements out of which all substances are composed and the conditions under which, and the mechanisms by which, substances are transformed into new substances. Chemists study pure substances, elements and compounds, molecules, atoms, and sub-atomic particles. They study chemical reactions, classes of chemicals, and uses for chemicals. Chemistry, like physics, conducts its study of the physical properties of chemical substances insofar as the properties of these substances can be measured, expressed in mathematical formulas (or approximations), and explained by chemical theories. Its goals may be roughly contrasted with those of physics (which focuses on physical properties, on the physical nature of matter and energy).

Its Key Question is: What are the chemical properties of pure substances insofar as they can be measured, expressed in mathematical formulas, and explained by chemical theories?

Its Key Concepts: Chemical theory is based on a conception of atoms, their electronic structures, and their spatial arrangements in molecules. Other key concepts include matter, energy, gravity, physical property, chemical property, pure substance, element, compound, molecule, reaction, electron, electron transfer, electron sharing, chemical bonding, atomic weight, molecular weight, specific gravity, valence, catalysis, qualitative analysis, quantitative analysis, organic compound, and inorganic compound.

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 all (or most) of the changes in identity of substances, as they react with other substances, can be accounted for by the theories and laws of modern chemistry.

The Data Chemists Gather result from their observations of the physical and chemical properties of matter. They observe matter as divided into elements and compounds. They seek to gather information about pure substances, molecules, atoms, and subatomic particles. They compare the behavior of different molecules. They observe the speed of chemical reactions within plants and animals. They observe the extent to which helping agents are necessary for these reactions to take place.

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

Implications. The huge growth in knowledge and understanding of the chemical world as a result of advances in chemistry carries with it important implications for quality of life in many dimensions of human existence. Chemical knowledge has had significant implications in medicine, agriculture, engineering, and biology. Many new substances and materials have been produced through chemistry. Our knowledge of chemistry has also been misused in the building of weapons of mass destruction (biochemical weapons), in our polluting of the environment, and in creating chemicals harmful to people, other animals, and plants.

The Point of View. Chemists see the physical world as containing basic elements whose structures can be studied and transformed in accordance with various chemical laws and principles.