"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

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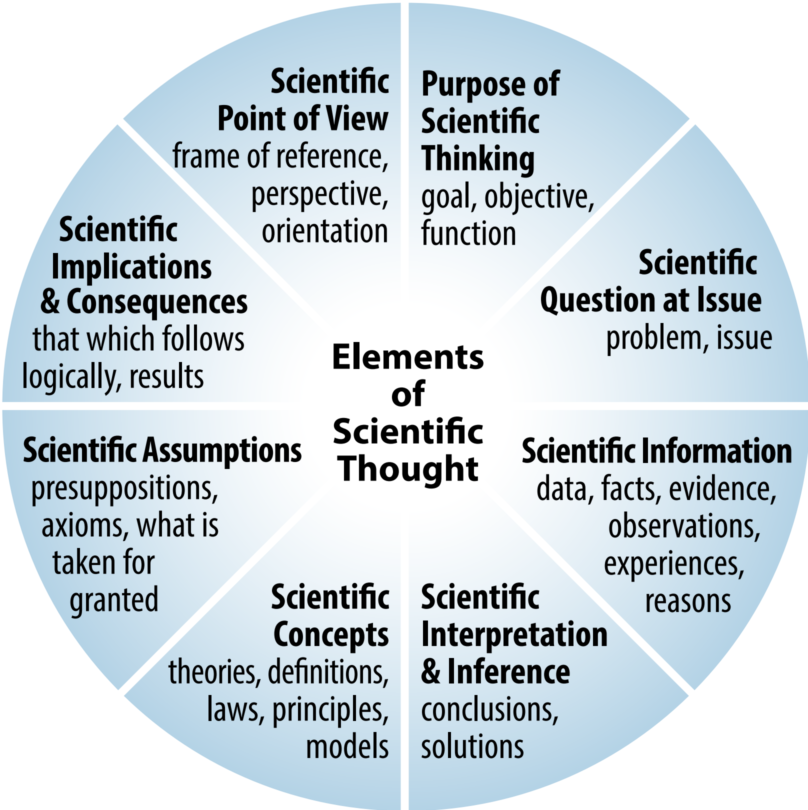
FOUNDATION FOR CRITICAL THINKING

The Elements of Scientific Thought



Used With Sensitivity to Universal Intellectual Standards

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

Questions Using the Elements of Scientific Thought

(in a scientific paper)

Scientific Purpose	What am I trying to accomplish? What is my central aim? My purpose?
Scientific Questions	What question am I raising? What question am I addressing? Am I considering the complexities in the question?
Scientific Information	What data am I using in coming to that conclusion? What information do I need to settle the question? What evidence is relevant to the question?
Scientific Inferences/ Conclusions	How did I reach this conclusion? Is there another way to interpret the information?
Scientific Concepts	What is the main concept, theory, or principle here? Can I explain the relevant theory?
Assumptions	What am I taking for granted? What assumption has led me to that conclusion?
Implications/ Consequences	What are the implications of the data I have collected? What are the implications of my inferences?
Points of View	From what point of view am I looking at this issue? Is there another point of view I should consider?

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.

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 maner can a body of dependable scientific knowledge be built up.
>
> *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

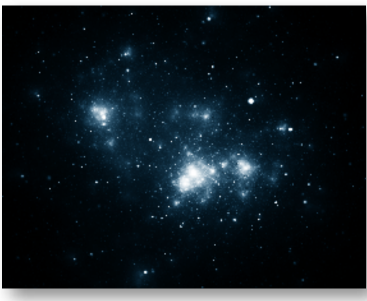
temperature, the volume is inversely related to the pressure applied to it; in other words, the greater the pressure the less the volume — the greater the volume the less the pressure. This relationship is constant for most gases within a moderate range of pressure. This relationship is known as *Boyle's 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 Formulate General Hypotheses or Physical Theories.** A theoretical generalization is formulated (if one is found to be plausible). For example, the *kinetic theory* of gas was formulated to explain what is documented in *Boyle's Law*. According to this theory, gases are aggregates of discrete molecules that incessantly fly about and collide with themselves and the wall of the container that holds them. The smaller the space they are forced to occupy, the greater the number of collisions against the surfaces of the space.

7. **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.

8. **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 holds that all species of plants and animals develop from earlier forms by hereditary transmission of slight variations in successive generations and that natural selection determines which forms will survive.



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 a number of universal standards, 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 "Most creatures with a spine are over 300 pounds in weight."

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.

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). For example, the statement "Just Say No" which is often used to discourage children and teens from using drugs, is clear, accurate, precise, and relevant. Nevertheless, it lacks depth because it treats an extremely complex issue, the pervasive problem of drug use among young people, superficially. It fails to deal with the complexities of the issue.

Breadth:

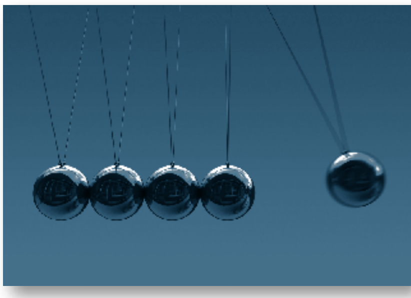
Do we need to consider another point of view? Is there another way to look at this question? What would this look like from the point of view of a conflicting theory, hypothesis or conceptual scheme?

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." 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

Clarity

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?

Accuracy

Free from errors or distortions, true
How could we check on those data?
How could we verify or test that theory?

Precision

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?

Relevance

Relating to the matter at hand
How do those data relate to the problem? How do they bear on the question?

Depth

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

Breadth

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?

Logic

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?

Significance

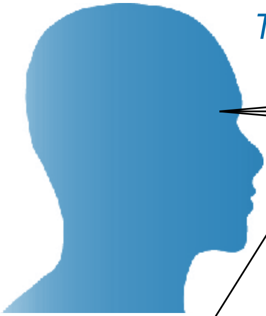
Focusing on the important, not trivial
Is this the central idea to focus on? Which set of data is most important?

Fairness

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

Thinking Scientifically



Object

The thing must have a logic…
something to figure out…

There is a logic to figuring something out scientifically, to constructing a system of meanings which makes sense of something

There are **intellectual standards** scientists use to assess whether the logic in their mind mirrors the logic of the thing to be understood

The Elements of Thought reveal the logic:

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

Intellectual Standards include:

Clarity

Precision

Relevance

Accuracy

Depth

Breadth

Logic

Fairness

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

One important way to understand a scientific essay, article or chapter is through the analysis of the structure of the author's reasoning. Once you have done this, you can evaluate the author's reasoning using intellectual standards (see page 20). Here is a template to follow:

1) The main **purpose** of this scientific article is __________________. (Here you are trying to state, as accurately as possible, the author's intent in writing the article. What was the author trying to accomplish?)

2) The key **question** that the author is addressing is __________________________. (Your goal is to figure out the key question that was in the mind of the author when he/she wrote the article. What was the key question addressed in the article?)

3) The most important **information** in this scientific article is __________________________. (You want to identify the key information the author used, or presupposed, in the article to support his/her main arguments. Here you are looking for facts, experiences, and/or data the author is using to support his/her conclusions.)

4) The main **inferences** in this scientific article are _____________________ ____. (You want to identify the most important conclusions the author comes to and presents in the article).

5) The key **concept**(s) we need to understand in this scientific article is (are) __________________________By these concepts the author means ____ _________________________________. (To identify these ideas, ask yourself: What are the most important ideas that you would have to know to understand the author's line of reasoning? Then briefly elaborate what the author means by these ideas.)

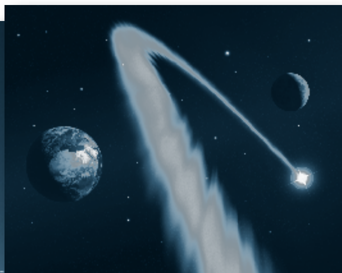
6) The main **assumption**(s) underlying the author's thinking is (are) _______________ (Ask yourself: What is the author taking for granted [that might be questioned]? The assumptions are generalizations that the author does not think he/she has to defend in the context of writing the article, and they are usually unstated. This is where the author's thinking logically begins.)

7a) If we accept this line of reasoning (completely or partially), the **implications** are _________________. (What consequences are likely to follow if people take the author's line of reasoning seriously? Here you are to pursue the logical implications of the author's position. You should include implications that the author states, and also those that the author does not state.)

7b) If we fail to accept this line of reasoning, the **implications** are ___________. (What consequences are likely to follow if people ignore the author's reasoning?)

8) The main **point(s) of view** presented in this scientific article is (are) ____________________. (The main question you are trying to answer here is: What is the author looking at, and how is he/she seeing it? For example, in this thinker's guide, we are looking at scientific thinking and seeing it "as requiring intellectual discipline and the development of intellectual skills.")

If you truly understand these structures as they interrelate in a scientific article, essay or chapter, you should be able to empathically role-play the thinking of the author. Remember, these are the eight basic structures that define all reasoning. They are the essential elements of scientific thought.



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)___________

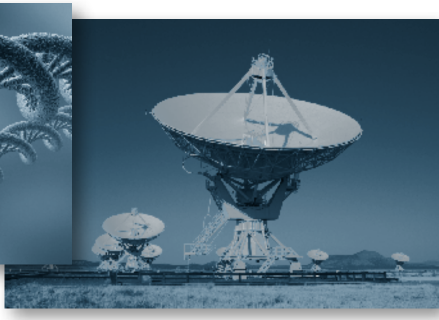
   ____.

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 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.



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) support 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________________________

____

____

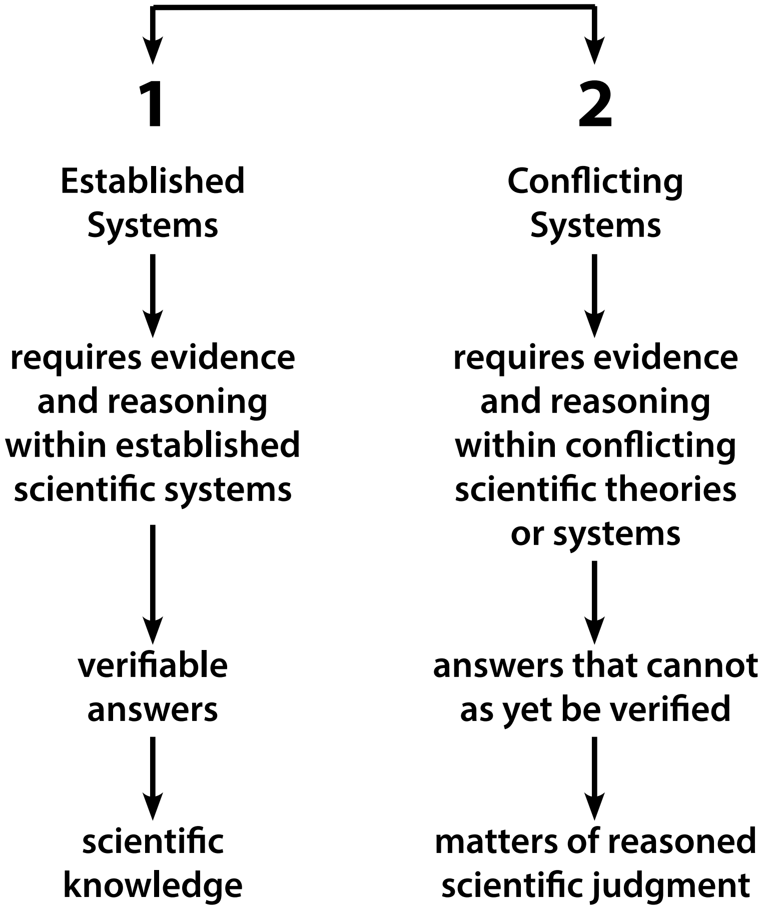
____.

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** or conclusions: 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 conclusions 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 scientific 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?

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.

The Questioning Mind in Science

Newton, Darwin, and Einstein[1]

Most people think that genius is the primary determinant of intellectual achievement. Yet three of the most distinguished thinkers had in common, not inexplicable genius, but a questioning mind. Their intellectual skills and inquisitive drive embodied the essence of critical thinking. Through skilled deep and persistent questioning they redesigned our view of the physical world and the universe.

Consider Newton. Uninterested in the set curriculum at Cambridge, Newton at 19 drew up a list of questions under 45 heads. His title: "Quaestiones," signaled his goal: constantly to question the nature of matter, place, time, and motion. His style was to slog his way to knowledge. For example, he "bought Descartes's Geometry and read it by himself. When he got over two or three pages he could understand no farther, then he began again and advanced farther and continued so doing till he made himself master of the whole…"

When asked how he had discovered the law of universal gravitation, he said: "By thinking on it continually." I keep the subject constantly before me and wait till the first dawnings open slowly, by little and little, into a full and clear light." This pattern of consistent, almost relentless questioning, led to depth of understanding and reconstruction of previous theories about the universe.

Newton acutely recognized knowledge as a vast field to be discovered: "I don't know what I may seem to the world, but, as to myself, I seem to have been only like a boy playing on the sea shore, and diverting myself in now and then finding a smoother pebble or prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."

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1 (Newton: The Life of Isaac Newton, by Richard Westfall, NY: Cambridge University Press,1993; The Autobiography of Charles Darwin, by Francis Darwin, NY: Dover Publications, 1958; A. Einstein: The Life and Times, by Ronald Clark, NY: Avon Books, 1984; A Variety of Men, by C.P. Snow, NY: Charles Scribners and Sons, 1967).)

Darwin's experience and approach to learning were similar to Newton's. First, he found traditional instruction discouraging. "During my second year at Edinburgh I attended lectures on Geology and Zoology, but they were incredibly dull. The sole effect they produced in me was the determination never as long as I lived to read a book on Geology, or in any way to study the science."

His experience at Cambridge was similar: "During the three years which I spent at Cambridge my time was wasted… The work was repugnant to me, chiefly from my not being able to see any meaning in [it]…"

Like Newton and Einstein, Darwin had a careful mind rather than a quick one:

"I have as much difficulty as ever in expressing myself clearly and concisely; and this difficulty has caused me a very great loss of time, but it has had the compensating advantage of forcing me to think long and intently about every sentence, and thus I have been led to see errors in reasoning and in my own observations or those of others."

In pursuing intellectual questions, Darwin relied upon perseverance and continual reflection, rather than memory and quick reflexes. "I have never been able to remember for more than a few days a single date or line of poetry." Instead, he had, "the patience to reflect or ponder for any number of years over any unexplained problem…At no time am I a quick thinker or writer: whatever I have done in science has solely been by long pondering, patience, and industry."

Einstein, for his part, did so poorly in school that when his father asked his son's headmaster what profession his son should adopt, the answer was simply, "It doesn't matter; he'll never make a success of anything." In high school, the regimentation "created in him a deep suspicion of authority. This feeling lasted all his life, without qualification."

Einstein commented that his schooling required "the obedience of a corpse." The effect of the regimented school was a clear-cut reaction by Einstein; he learned "to question and doubt." He concluded: "…youth is intentionally being deceived by the state through lies."

He showed no signs of being a genius, and as an adult denied that his mind was extraordinary: "I have no particular talent. I am merely extremely inquisitive." He failed his entrance examination to the Zurich Polytechnic. When he finally passed, "the examinations so constrained his mind that, when he had graduated, he did not want to think about scientific problems for a year." His final exam was so non-distinguished that afterward he was refused a post as an assistant (the lowest grade of postgraduate job).

Exam-taking, then, was not his forte. Questioning deeply and thinking critically was.

Einstein had the basic critical thinking ability to cut problems down to size: "one of his greatest intellectual gifts, in small matters as well as great, was to strip off the irrelevant frills from a problem."

When we consider the work of these three thinkers, Einstein, Darwin, and Newton, we find, not the unfathomable, genius mind. Rather we find thinkers who placed deep and fundamental questions at the heart of their work and pursued them passionately.

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 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 it.

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.

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.

The Logic of Paleontology

The Goal of Paleontology: Is to discover the nature and implications of fossils of animal and plant life that existed in remote geological times (from 600 million years ago to 2 million years ago).

Its Key Questions are: What can we learn about the development of plant and animal life by studying the fossil remains of animal and plant life from 600 million years ago to 2 million years ago? What is the life cycle, distribution, and evolutionary history of this or that particular plant or animal species?

Its Key Concepts include: ancient life form, paleozoic life forms, plant, animal, fossil, petrification, organic material, inorganic material, natural mold, carbon print, sedimentary deposit, geological deposit, fossil animal droppings, Cambrian period (600 million years ago), vertebrates, primitive forms of crustacean, mollusks, Ordovician period (500 million years ago), graptolites, colonial coelenterates, primitive fish, flora, fauna, Silurian period (430 million years ago), fish, scorpion, vacular plants, corals, Devonian period (395 million years ago) amphibians, Carboniferous period (345 million years ago) lizards and sharks, Permian period (280 million years ago) early reptiles, Mesozoic life, age of reptiles (begins 225 million years ago) Triassic period (225 million years ago) dinosaurs, Jurassic period (195 million years ago) dinosaurs, Cretaceous period (136 million years ago) horned dinosaurs, Cenozoic life, age of mammals (begins 65 million years ago), Eocene epoch (54 million years ago), Oligocene epoch (38 million years ago), Miocene epoch (26 million years ago), and Pleistocene epoch (12 million years ago).

Its Key Assumptions are: That plant and life forms originated on earth, that this evolution took place over some 600 million years; that paleontology can be understood through studying fossil remains from distinctive periods of time in that 600 million years; that paleontology gives a true but incomplete record of the development of existing life forms; and that throughout geological time successive plants and animals have tended to become more complex.

The Data or Information Paleontologists Gather are of and from the actual remains of living organisms preserved and protected from decay by enclosure in the crust of the earth through fossilization (ancient plants and animals embedded in mineral deposits). Paleontologists rely on basic information from geology and biology in conducting their investigations.

Inferences, Generalizations, or Hypotheses are made regarding the ancient evolution of plant and life forms. It is in general inferred that life in the sea evolved from primitive multicellular free-floating forms to advanced groups capable of life on land (from fossil remains in rock strata of the Paleozoic era) and that each group of animals begins with simple types, that gradually more complex and specialized forms appear, and that frequently decadence sets in with great suddenness, resulting in extinction or the reduction of the group to relative unimportance.

Implications: The huge growth in knowledge and understanding of the evolution of the plant and animal world as a result of advances in Paleontology carries with it important implications for understanding the basis for human evolution. Paleontology has also made a significant contribution to our understanding of ecosystems and their fragility. Certain fossils are so characteristic of the different periods, epochs, or formations of rocks that they serve as index fossils enabling the geologist to fix the geological age of the rocks from which they come.

The Point of View of Paleontology: Paleontologists see the development of plants and animals occurring over millions of years and the study of this evolutionary process as an ongoing, dynamic process.

The Logic of Animal Physiology

Goals of Animal Physiologists: To figure out how living organisms work, including the physical and chemical processes that take place in living organisms during the performance of life functions. Physiology investigates biological mechanisms with the tools of physics and chemistry. It is closely related to anatomy, though physiologists focus on bodily functions; anatomists on bodily structures. General physiologists focus on the basic functions common to all life. Physiologists may focus on particular life forms, pathology, or comparative studies. (Plant physiology, a branch of botany, focuses on the life functions within plants.)

Questions Animal Physiologists Ask: What are the basic functions common to all life? What physical and chemical processes take place in living organisms during the performance of life functions? What happens in a body during reproduction, growth, metabolism, respiration, digestion, excitation, and contraction? What happens during these functions within the bodies' cells, tissues, organs, or within organ or nerve systems? In what ways can life functions be disrupted, injured, or diseased?

Information Animal Physiologists Use: The main information obtained by physiologists is from the direct study of physical and chemical processes as these take place in living organisms during the performance of life functions. They observe cells, tissue, and organs microscopically. They observe them in artificial and real-life environments. They compare structures and functions of life processes.

Judgments Animal Physiologists Make: Physiologists make judgments about functions common to all life forms as well as differences among them. They judge how these functions best perform and thrive. They make judgments about pathologies and interpret how internal systems and functions interrelate with environment realities.

Concepts that Guide Animal Physiologists' Thinking: The most fundamental concept in physiology is the concept of bodily functions in systemic relations. Other important concepts used to guide physiological thinking are: reproduction, growth, metabolism, respiration, blood circulation, nutrition, digestion, excretion, excitation, contraction, cells, tissues, nerves, muscles, bones, organs, systems of organs, organ and system pathology.

Key Assumptions Animal Physiologists Make: Physiologists make the following assumptions: 1) living things must perform a specifiable group of common and essential functions; 2) different species of living things perform various common functions in different and sometimes unique ways (through diverse cell, tissue, and organ structures); and, 3) it is possible for physiologists to accurately describe, test, and verify their descriptions and theories concerning functions performed within animal systems.

Implications of Animal Physiology: The implications of human physiology are interconnected with those of bacteriology, immunology, chemistry, and physics, among other scientific branches. Physiologists who study animal functions have made numerous discoveries about bodily functions (such as the heart, brain,and other organs) which have led to advancements in medical treatment. The implications for medical care, for human and veterinary medicine, through physiological study, are virtually unlimited.

The Point of View of Physiologists: Physiologists see life functions as systems working harmoniously to perform essential processes. They also see pathology within living systems as a breakdown in this harmonious process which, when studied, can lead to less pathology and improved life quality.

The Logic of Archaeology

Purpose of the Thinking: The purpose of archaeology is to find remnants of the past, interpreting and piecing them together in order to discover more about historical events, culture, and our human legacy.

Question at Issue: What is the best way to find information about the distant past, and how does one effectively interpret the past through archaeology?

Information: In order to become or think like an effective archaeologist, one should consider site discovery techniques, artifact retrieval, cataloging, and preservation techniques, contextual and cultural clues, and supportable historical and scientific data from archaeological finds.

Interpretation and Inference: Archaeologists formulate historical interpretations and validate them by cross-referencing various previous interpretations, current cultural evidence, physical artifacts and scientific data from archaeological finds.

Concepts: The concept of recovering lost history, of seeking evidence from beneath the surface of the earth to reveal important events and time sequences in ancient human history.

Assumptions: We can always enrich our understanding of the past, and archaeology provides evidence to support historical theories. The past is a puzzle that can be further solved through ongoing archaeological study.

Implications and Consequences: New discoveries that answer questions of the past can be made with on-going archaeological research. Beliefs we now hold as true, could one day be revised based on future discoveries. Understanding old ways of doing things may also provide the present or future with useful knowledge or resources for survival.

Point of View: Seeing the story of humankind as taking place through stages over hundreds of thousands of years.

The Logic of Ecology

Goals of Ecologists: Ecologists seek to understand plants and animals as they exist in nature, with emphasis on their interrelationships, interdependence, and interactions with the environment. They work to understand all the influences that combine to produce and modify an animal or given plant, and thus to account for its existence and peculiarities within its habitat.

Questions Ecologists Ask: How do plants and animals interact? How do animals interact with each other? How do plants and animals depend on one another? How do the varying ecosystems function within themselves? How do they interact with other ecosystems? How are plants and animals affected by environmental influences? How do animals and plants grow, develop, die, and replace themselves? How do plants and animals create balances between each other? What happens when plants and animals become unbalanced?

Information Ecologists Use: The primary information used by ecologists is gained through observing plants and animals themselves, their interactions, and how they live within their environments. Ecologists note how animals and plants are born, how they reproduce, how they die, how they evolve, and how they are affected by environmental changes. They also use information from other disciplines including chemistry, meteorology, and geology.

Judgments Ecologists Make: Ecologists make judgments about how ecosystems naturally function, about how animals and plants within them function, about why they function as they do. They make judgments about how ecosystems become out of balance and what can be done to bring them back into balance. They make judgments about how natural communities should be grouped and classified.

Concepts that Guide Ecologists' Thinking: One of the most fundamental concepts in ecology is ecosystem. Ecosystem is defined as a group of living things, dependent on one another and living in a particular habitat. Ecologists study how differing ecosystems function. Another key concept in ecology is ecological succession, the natural pattern of change occurring within every ecosystem when natural processes are undisturbed. This pattern includes the birth, development, death, and then replacement of natural communities. Ecologists have grouped communities into larger units called biomes. These are regions throughout the world classified according to physical features, including temperature, rainfall, and type of vegetation. Another fundamental concept in ecology is balance of nature, the natural process of birth, reproduction, eating and being eaten, which keeps animal/plant communities fairly stable. Other key concepts include imbalances, energy, nutrients, population growth, diversity, habitat, competition, predation, parasitism, adaptation, coevolution, succession and climax communities, and conservation.

Key Assumptions Ecologists Make: That patterns exist within animal/plant communities; that these communities should be studied and classified; that animals and plants often depend on one another and modify one another; and that balances must be maintained within ecosystems.

Implications of Ecology: The study of ecology leads to numerous implications for life on earth. By studying balance of nature, for example, we can see when nature is out of balance, as in the current population explosion. We can see how pesticides, designed to kill pests on farm crops, also lead to the harm of mammals and birds, either directly or indirectly through food webs. We can also learn how over-farming causes erosion and depletion of soil nutrients.

The Point of View of Ecologists: Ecologists look at plants and animals and see them functioning in relationship with one another within their habitats, and needing to be in balance for the earth to be healthy and sustainable.

The Problem of Pseudo-Scientific and Unscientific Thinking

Unscientific and pseudo-scientific thinking come from the unfortunate fact that humans do not naturally think scientifically, though they often think they do. Furthermore, we become explicitly aware of our unscientific thinking only if trained to do so. We do not naturally recognize our assumptions, the unscientific way we use information, the way we interpret data, the source of our concepts and ideas, the implications of our unscientific thought. We do not naturally recognize our unscientific perspective.

As humans we live with the unrealistic but confident sense that we have fundamentally figured out the true nature of things, and that we have done this objectively. We naturally believe in our intuitive perceptions — however inaccurate. Instead of using intellectual standards in thinking, we often use self-centered psychological standards to determine what to believe and what to reject. Here are the most commonly used psychological standards in unscientific human thinking.

"IT'S TRUE BECAUSE I BELIEVE IT." I assume that what I believe is true even though I have never questioned the basis for my beliefs.

"IT'S TRUE BECAUSE WE BELIEVE IT." I assume that the dominant beliefs within the groups to which I belong are true even though I have never questioned the basis for many of these beliefs.

"IT'S TRUE BECAUSE I WANT TO BELIEVE IT." I believe in, for example, accounts of behavior that put me (or the groups to which I belong) in a positive rather than a negative light even though I have not seriously considered the evidence for the more negative account. I believe what "feels good," what supports my other beliefs, what does not require me to change my thinking in any significant way, what does not require me to admit I have been wrong.

"IT'S TRUE BECAUSE I HAVE ALWAYS BELIEVED IT." I have a strong desire to maintain beliefs that I have long held, even though I have not seriously considered the extent to which those beliefs are justified, given the evidence.

"IT'S TRUE BECAUSE IT IS IN MY INTEREST TO BELIEVE IT." I hold fast to beliefs that justify my getting more power, money, or personal advantage even though these beliefs are not grounded in sound reasoning or evidence.

Since humans are naturally prone to assess thinking in keeping with the above criteria, it is not surprising that unscientific thinking flourishes in our society.

A Pseudo-Science: Why Astrology Is Not a Science[2]

The claims of astrologers are rejected by the scientific community. Astrology is popular, nevertheless. Though most adults have taken many science classes in school, few know how to assess the claims of astrologers scientifically. In fact, many students, and even teachers, believe that astrology provides accurate personality descriptions and valuable advice. Noted astrologers earn a sizeable income as consultants. To many, the personality descriptions based on horoscopes seem to fit. As people read the descriptions of personality traits attributed to those born under their "sun sign," they examine themselves and find they have many of the traits depicted. What they do not do is look to see if descriptions associated with other signs of the Zodiac might fit them equally well. Likewise, when they are told that at the present time in their lives they are going through some stress or have to make a major decision, they tend to agree with the astrologer, without examining their lives to see if the same description would fit almost any other period of their lives.

Simply telling students that most scientists consider astrology invalid will not convince them that it is. After learning about controlled research, students should be able to see the defects in conventional astrological research. They should also be able to identify research designs capable of scientifically testing astrological theories.

Scientists agree that the positions of the sun, moon, and possibly even some nearby planets affect living organisms—but not in the ways claimed by astrologers. Carefully controlled studies of predictions based on astrological theories have almost always yielded negative results.

Astrology began thousands of years ago in ancient Babylonia, Persia, Greece, and Rome. Before true scientific knowledge existed, and before what we call the 'scientific method' was devised, these people tried to organize their knowledge of the stars by perceiving in them shapes of animals and persons, such as a lion, ram, crab, fish, scorpion, archer, water carrier, twins, etc. The ancients assumed that the arrangement of stars into the shapes of animals and persons had cosmic significance.

They noticed that during the day the sun passed through the areas in which these shapes were observed at night, and this varied at different times of the year. The band of these shapes that the sun passed through was called the 'Zodiac,' and these animals or persons were called the 'signs of the Zodiac.' For awhile the sun was in the area of a constellation shaped like fishes, a month later the sun would be in a constellation which had stars that reminded them of a water carrier. It was believed that constellations were powerful when the sun was in their area. Thus if the sun was in the constellation shaped like a lion, this cosmic animal would have a powerful influence on earthly events.

2 These ideas were originally formulated by Dr. Wesley Hiler.

These ancients noticed that some lights in the sky moved across the stable arrangement of the other lights, so they called these 'wanderers' or 'planets' and imagined that they were gods or the abodes of gods. The sun was worshiped as the chief god in some of these lands. They noticed that one of the planets was reddish in color so they named it after the god of war, Mars.

Astronomers in these ancient civilizations assumed that the arrangement of stars, planets, sun, and moon influenced events taking place on earth at the time. Specifically the arrangement of these heavenly bodies at the time of an individual's birth would influence his or her personality and fate. The arrangement of heavenly bodies at any given time is called a 'horoscope.' It was assumed that if astrologers knew the time and place of an individual's birth they could make predictions concerning that person's character and destiny. For instance, if a person was born when the sun was in the part of the sky where the stars were arranged in the shape of a lion, the person would have personality traits similar to those of a lion. The region of the Zodiac where the sun was at the time of a person's birth is referred to as the individual's 'sun sign.' Sun signs are the most commonly used sources of astrological inferences. Many newspapers contain advice geared to a person's sun sign.

The theories developed by ancient astrologers were passed on through tradition, without any carefully controlled scientific verification, generation after generation. Because of the enormous number of variables in a horoscope, and the many possible ways of interpreting each one, an astrologer can select the interpretation he believes best fits a known individual. Therefore astrologers are quite accurate in matching their predictions with famous people of the past whose time and place of birth are known to them. They are less accurate in using horoscopes to make inferences about the personalities and lives of people unknown to them. Most books on astrology contain chapters on famous people like Hitler or Napoleon, in which the astrologer is able to match their lives with inferences derived from the arrangement of the stars at the times of their births and at times during their lives.

Astrological method differs from scientific method in many ways:

1) Astrological interpretations are not derived from natural laws but from symbolic relationships. According to astrology, a person born when the sun, moon, or any planets were in a constellation which looked like a ram would have personality traits similar to a ram.
2) Astrologers seek correspondences between astrological theory and what is known about someone and ignore lack of correspondence.

3) Astrologers do not conduct carefully controlled research to see if their personality assessments and predictions are more accurate than one could expect by chance alone.
4) Some personality descriptions are so general that they fit everyone. Everyone has some traits of all the sun signs, so people can find descriptions which fit them in every sun sign.
5) People can find any tendency in themselves if they look hard enough. They see what they expect to see. Their knowledge of astrology affects how they see themselves.
6) People jump to conclusions on the basis of small samples. They tend to remember what fits their expectations, but forget what doesn't.

How could the arrangement of stars as seen from the earth could have any effect on events taking place on earth; for instance, how could a lion shaped arrangement of stars influence events in a lion like fashion? Nevertheless, Sydney Omarr, a well known and highly influential astrologist, wrote books on the twelve signs of the zodiac which sold 50 million copies world-wide.[3]

3 *The Press Democrat*, Jan. 3, 2003, p. B2.

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