Basic Concepts

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Abductive reasoning

Abduction is a kind of logical inference described by Charles Sanders Peirce as "guessing"[1] . The term refers to the process of arriving at an explanatory hypothesis. Peirce said that to *abduce* a hypothetical explanation a from an observed surprising circumstance b is to surmise that a may be true because then b would be a matter of course.[2] Thus, to abduce a from b involves determining that a is sufficient (or nearly sufficient), but not necessary, for b .

For example, *the lawn is wet*. But if *it rained last night*, then it would be unsurprising that *the lawn is wet*. Therefore, by abductive reasoning, *it rained last night*. (But note that Peirce did not remain convinced that a single logical form covers all abduction.)[3]

Peirce argues that good abductive reasoning from *P* to *Q* involves not simply a determination that, e.g., *Q* is sufficient for *P*, but also that *Q* is among the most economical explanations for *P*. Simplification and economy are what call for the 'leap' of abduction.[4]

There has been renewed interest in the subject of abduction in the fields of computer science and artificial intelligence research.[5]

Deduction, induction, and abduction

Deduction

allows deriving b from a only where b is a formal consequence of a. In other words, deduction is the process of deriving the consequences of what is assumed. Given the truth of the assumptions, a valid deduction guarantees the truth of the conclusion. For example, given that all bachelors are unmarried males, and given that this person is a bachelor, it can be deduced that this person is an unmarried male.

Induction

allows inferring b from a , where b does not follow necessarily from a . a might give us very good reason to accept b , but it does not ensure that b . For example, if all of the swans that we have observed so far are white, we may induce that all swans are white. We have good reason to believe the conclusion from the premise, but the truth of the conclusion is not guaranteed. (Indeed, it turns out that some swans are black.)

Abduction

allows inferring a as an explanation of b . Because of this, abduction allows the precondition a to be abduced from the consequence b . Deduction and abduction thus differ in the direction in which a rule like " a entails b " is used for inference. As such abduction is formally equivalent to the logical fallacy affirming the consequent or *Post hoc ergo propter hoc*, because there are multiple possible explanations for b . For example, after glancing up and seeing the eight ball moving towards us we may abduce that it was struck by the cue ball. The cue ball's strike would account for the eight ball's movement. It serves as a theory that explains our observation. There are in fact infinitely many possible explanations for the eight ball's movement, and so our abduction does not leave us certain that the cue ball did in fact strike the eight ball, but our abduction is still useful and can serve to orient us in our surroundings. This process of abduction is an instance of the scientific method. There are infinite possible explanations for any of the physical processes we observe, but we are inclined to abduce a single explanation (or a few explanations) for them in the hopes that we can better orient ourselves in our surroundings and eliminate some of the possibilities.

Formalizations of abduction

Logic-based abduction

In logic, explanation is done from a logical theory T representing a domain and a set of observations O. Abduction is the process of deriving a set of explanations of O according to T and picking out one of those explanations. For E to be an explanation of O according to T, it should satisfy two conditions:

- O follows from E and T;
- E is consistent with T.

In formal logic, O and E are assumed to be sets of literals. The two conditions for E being an explanation of O according to theory T are formalized as:

$T \cup E \models O$;

$T \cup E$ is consistent.

Among the possible explanations E satisfying these two conditions, some other condition of minimality is usually imposed to avoid irrelevant facts (not contributing to the entailment of O) being included in the explanations. Abduction is then the process that picks out some member of E. Criteria for picking out a member representing "the best" explanation include the simplicity, the prior probability, or the explanatory power of the explanation.

A proof theoretical abduction method for first order classical logic based on the sequent calculus and a dual one, based on semantic tableaux (analytic tableaux) have been proposed (Cialdea Mayer & Pirri 1993). The methods are sound and complete and work for full first order logic, without requiring any preliminary reduction of formulae into normal forms. These methods have also been extended to modal logic.

Abductive logic programming is a computational framework that extends normal logic programming with abduction. It separates the theory T into two components, one of which is a normal logic program, used to generate E by means of backward reasoning, the other of which is a set of integrity constraints, used to filter the set of candidate explanations.

Set-cover abduction

A different formalization of abduction is based on inverting the function that calculates the visible effects of the hypotheses. Formally, we are given a set of hypotheses H and a set of manifestations M; they are related by the domain knowledge, represented by a function e that takes as an argument a set of hypotheses and gives as a result the corresponding set of manifestations. In other words, for every subset of the hypotheses $H' \subseteq H$, their effects are known to be $e(H')$.

Abduction is performed by finding a set $H' \subseteq H$ such that $M \subseteq e(H')$. In other words, abduction is performed by finding a set of hypotheses H' such that their effects $e(H')$ include all observations M.

A common assumption is that the effects of the hypotheses are independent, that is, for every $H' \subseteq H$, it holds that $e(H') = \bigcup_{h \in H'} e(\{h\})$. If this condition is met, abduction can be seen as a form of set covering.

Abductive validation

Abductive validation is the process of validating a given hypothesis through abductive reasoning. This can also be called reasoning through successive approximation. Under this principle, an explanation is valid if it is the best possible explanation of a set of known data. The best possible explanation is often defined in terms of simplicity and elegance (see Occam's razor). Abductive validation is common practice in hypothesis formation in science; moreover, Peirce argues it is a ubiquitous aspect of thought:

> Looking out my window this lovely spring morning I see an azalea in full bloom. No, no! I do not see that; though that is the only way I can describe what I see. That is a proposition, a sentence, a fact; but what I perceive is not proposition, sentence, fact, but only an image, which I make intelligible in part by means of a statement of fact. This statement is abstract; but what I see is concrete. I perform an abduction when I so much as express in a sentence anything I see. The truth is that the whole fabric of our knowledge is one matted felt of pure hypothesis confirmed and refined by induction. Not the smallest advance can be made in knowledge beyond the stage of vacant staring, without making an abduction at every step.[6]

It was Peirce's own maxim that "Facts cannot be explained by a hypothesis more extraordinary than these facts themselves; and of various hypotheses the least extraordinary must be adopted."[7] After obtaining results from an inference procedure, we may be left with multiple assumptions, some of which may be contradictory. Abductive validation is a method for identifying the assumptions that will lead to your goal.

Probabilistic abduction

Probabilistic abductive reasoning is a form of abductive validation, and is used extensively in areas where conclusions about possible hypotheses need to be derived, such as for making diagnoses from medical tests. For example, a pharmaceutical company that develops a test for a particular infectious disease will typically determine the reliability of the test by letting a group of infected and a group of non-infected people undergo the test. Assume the statements x: "Positive test", $\overline{x}$: "Negative test", y: "Infected", and $\overline{y}$: "Not infected". The result of these trials will then determine the reliability of the test in terms of its sensitivity $p(x|y)$ and false positive rate $p(x|\overline{y})$. The interpretations of the conditionals are: $p(x|y)$: "The probability of positive test given infection", and $p(x|\overline{y})$: "The probability of positive test in the absence of infection". The problem with applying these conditionals in a practical setting is that they are expressed in the opposite direction to what the practitioner needs. The conditionals needed for making the diagnosis are: $p(y|x)$: "The probability of infection given positive test", and $p(y|\overline{x})$: "The probability of infection given negative test". The probability of infection could then have been conditionally deduced as $p(y\|x) = p(x)p(y|x) + p(\overline{x})p(y|\overline{x})$, where " $\|$ " denotes conditional deduction. Unfortunately the required conditionals are usually not directly available to the medical practitioner, but they can be obtained if the base rate of the infection in the population is known.
The required conditionals can be correctly derived by inverting the available conditionals using Bayes rule. The inverted conditionals are obtained as follows: $\begin{cases} p(x|y) = \frac{p(x \wedge y)}{p(y)} \\ p(y|x) = \frac{p(x \wedge y)}{p(x)} \end{cases} \Rightarrow \quad p(y|x) = \dfrac{p(y)p(x|y)}{p(x)}$. The term $p(y)$ on the right hand side of the equation expresses the base rate of the infection in the population. Similarly, the term $p(x)$ expresses the default likelihood of positive test on a random person in the population. In the expressions below $a(y)$ and $a(\overline{y}) = 1 - a(y)$ denote the base rates of y and its complement $\overline{y}$ respectively, so that e.g. $p(x) = a(y)p(x|y) + a(\overline{y})p(x|\overline{y})$. The full expression for the required conditionals $p(y|x)$ and $p(y|\overline{x})$ are then: $\begin{cases} p(y|x) = \frac{a(y)p(x|y)}{a(y)p(x|y)+a(\overline{y})p(x|\overline{y})} \\ p(y|\overline{x}) = \frac{a(y)p(\overline{x}|y)}{a(y)p(\overline{x}|y)+a(\overline{y})p(\overline{x}|\overline{y})} \end{cases}$
The full expression for the conditionally abduced probability of infection in a tested person, expressed as $p(y\overline{\|}x)$, given the outcome of the test, the base rate of the infection, as well as the test's sensitivity and false positive rate, is then given by: .
Probabilistic abduction can thus be described as a method for inverting conditionals in order to apply probabilistic deduction.

A medical test result is typically considered positive or negative, so when applying the above equation it can be assumed that either $p(x) = 1$ (positive) or $p(\overline{x}) = 1$ (negative). In case the patient tests positive, the above equation can be simplified to $p(y\overline{\|}x) = p(y|x)$ which will give the correct likelihood that the patient actually is infected.

The Base rate fallacy in medicine,[8] or the Prosecutor's fallacy[9] in legal reasoning, consists of making the erroneous assumption that $p(y|x) = p(x|y)$. While this reasoning error often can produce a relatively good approximation of the correct hypothesis probability value, it can lead to a completely wrong result and wrong conclusion in case the base rate is very low and the reliability of the test is not perfect. An extreme example of the base rate fallacy is to conclude that a male person is pregnant just because he tests positive in a pregnancy test. Obviously, the base rate of male pregnancy is zero, and assuming that the test is not perfect, it would be correct to conclude that the male person is not pregnant.

The expression for probabilistic abduction can be generalised to multinomial cases,[10] i.e., with a state space X of multiple x_i and a state space Y of multiple states y_j .

Subjective logic abduction

Subjective logic generalises probabilistic logic by including parameters for uncertainty in the input arguments. Abduction in subjective logic is thus similar to probabilistic abduction described above.[10] The input arguments in subjective logic are composite functions called subjective opinions which can be binomial when the opinion applies to a single proposition or multinomial when it applies to a set of propositions. A multinomial opinion thus applies to a frame X (i.e. a state space of exhaustive and mutually disjoint propositions x_i), and is denoted by the composite function $\omega_X = (\vec{b}, u, \vec{a})$, where $\vec{b}$ is a vector of belief masses over the propositions of X , u is the uncertainty mass, and $\vec{a}$ is a vector of base rate values over the propositions of X . These components satisfy $u + \sum \vec{b}(x_i) = 1$ and $\sum \vec{a}(x_i) = 1$ as well as $\vec{b}(x_i), u, \vec{a}(x_i) \in [0, 1]$.

Assume the frames X and Y, the sets of conditional opinions $\omega_{X|Y}$ and $\omega_{X|\overline{Y}}$, the opinion ω_X on X , and the base rate function a_Y on Y. Based on these parameters, subjective logic provides a method for deriving the set of inverted conditionals $\omega_{Y|X}$ and $\omega_{Y|\overline{X}}$. Using these inverted conditionals, subjective logic also provides a method for deduction. Abduction in subjective logic consists of inverting the conditionals and then applying deduction.

The symbolic notation for conditional abduction is " $\overline{\|}$ ", and the operator itself is denoted as $\overline{\circledcirc}$. The expression for subjective logic abduction is then:[10] $\omega_{Y\overline{\|}X} = \omega_X \; \overline{\circledcirc} \; (\omega_{X|Y}, \omega_{X|\overline{Y}}, a_Y)$.

The advantage of using subjective logic abduction compared to probabilistic abduction is that uncertainty about the probability values of the input arguments can be explicitly expressed and taken into account during the analysis. It is thus possible to perform abductive analysis in the presence of missing or incomplete input evidence, which normally results in degrees of uncertainty in the output conclusions.

History of the concept

The philosopher Charles Sanders Peirce (pronounced /ˈpɜrs/ like "purse") (1839–1914) introduced abduction into modern logic. Over the years he called such inference *hypothesis*, *abduction*, *presumption*, and *retroduction*. He considered it a topic in logic as a normative field in philosophy, not in purely formal or mathematical logic, and eventually as a topic also in economics of research.

As two stages of the development, extension, etc., of a hypothesis in scientific inquiry, abduction and induction are often collapsed into one overarching concept — the hypothesis. That is why, in the scientific method pioneered by Galileo and Bacon, the abductive stage of hypothesis formation is conceptualized simply as induction. In the twentieth century this collapse was reinforced by Karl Popper's explication of the hypothetico-deductive model, where the hypothesis is considered to be just "a guess"[11] (in the spirit of Peirce). However, when the formation of a hypothesis is considered the result of a process it becomes clear that this "guess" has already been tried and made more robust in thought as a necessary stage of its acquiring the status of hypothesis. Indeed many abductions are rejected or heavily modified by subsequent abductions before they ever reach this stage.

Before 1900, Peirce treated abduction as the use of a known rule to explain an observation, e.g., it is a known rule that if it rains the grass is wet; so, to explain the fact that the grass is wet; one infers that it has rained. This remains the common use of the term "abduction" in the social sciences and in artificial intelligence.

Peirce consistently characterized it as the kind of inference that originates a hypothesis by concluding in an explanation, though an unassured one, for some very curious or surprising (anomalous) observation stated in a premise. As early as 1865 he wrote that all conceptions of cause and force are reached through hypothetical inference; in the 1900s he wrote that all explanatory content of theories is reached through abduction. In other respects Peirce revised his view of abduction over the years.[12]

In later years his view came to be:

- Abduction is guessing.[1] It is "very little hampered" by rules of logic.[2] Oftenest even a well-prepared mind guesses wrong. But the success of our guesses far exceeds that of random luck and seems born of attunement to nature by instinct[13] (some speak of intuition in such contexts[14]).
- Abduction guesses a new or outside idea so as to account in a plausible, instinctive, economical way for a surprising or very complicated phenomenon. That is its proximate aim.[13]
- Its longer aim is to economize inquiry itself. Its rationale is inductive: it works often enough, is the only source of new ideas, and has no substitute in expediting the discovery of new truths.[15] Its rationale especially involves its role in coordination with other modes of inference in inquiry. It is inference to explanatory hypotheses for selection of those best worth trying.
- Pragmatism is the logic of abduction. Upon the generation of an explanation (which he came to regard as instinctively guided), the pragmatic maxim gives the necessary and sufficient logical rule to abduction in general. The hypothesis, being insecure, needs to have conceivable[16] implications for informed practice, so as to be testable[17] [18] and, through its trials, to expedite and economize inquiry. The economy of research is what calls for abduction and governs its art.[4]

Writing in 1910, Peirce admits that "in almost everything I printed before the beginning of this century I more or less mixed up hypothesis and induction" and he traces the confusion of these two types of reasoning to logicians' too "narrow and formalistic a conception of inference, as necessarily having formulated judgments from its premises."[19]

He started out in the 1860s treating hypothetical inference in a number of ways which he eventually peeled away as inessential or, in some cases, mistaken:

- as inferring the occurrence of a character (a characteristic) from the combined occurrence of multiple characters which it necessarily involves[20] (but by 1878 he no longer regarded that as common to all hypothetical inference.[21])
- as aiming for a more or less probable hypothesis (in 1867 and 1883 but not in 1878; anyway by 1900 the justification is not probability but the lack of alternatives to guessing and the fact that guessing is fruitful.[22] ; by 1903 he speaks of the "likely" in the sense of nearing the truth in an "indefinite sense"[23] ; by 1908 he discusses *plausibility* as instinctive appeal.[13])
- as induction from characters (but as early as 1900 he characterized abduction as guessing[22])
- as citing a known rule in a premise rather than hypothesizing a rule in the conclusion (but by 1903 he allowed either approach[24] [2])
- as basically a transformation of a deductive categorical syllogism[21] (but in 1903 he offered a variation on *modus ponens* instead[2] , and by 1911 he was unconvinced that any one form covers all hypothetical inference[3]).

In 1867, in "The Natural Classification of Arguments",[20] hypothetical inference always deals with a cluster of characters (call them P', P'', P''', etc.) known to occur at least whenever a certain character (M) occurs. (Note that categorical syllogisms have elements traditionally called middles, predicates, and subjects. For example: All *men* [middle] are *mortal* [predicate]; *Socrates* [subject] is a *man* [middle]; ergo *Socrates* [subject] is *mortal* [predicate]". Below, 'M' stands for a middle; 'P' for a predicate; 'S' for a subject. Note also that Peirce held that all deduction can be put into the form of the categorical syllogism Barbara (AAA).)

[Deduction].	Induction.	Hypothesis.
[Any] M is P [Any] S is M ∴[Any] S is P.	S', S'', S''', &c. are taken at random as *M*'s; S', S'', S''', &c. are *P*: ∴Any *M* is probably *P*.	Any *M* is, for instance, P', P'', P''', &c.; *S* is P', P'', P''', &c.: ∴*S* is probably *M*.

In 1878, in "Deduction, Induction, and Hypothesis"[21] , there is no longer a need for multiple characters or predicates in order for an inference to be hypothetical, although it is still helpful. Moreover Peirce no longer poses hypothetical inference as concluding in a *probable* hypothesis. In the forms themselves, it is understood but not explicit that induction involves random selection and that hypothetical inference involves response to a "very curious circumstance". The forms instead emphasize the modes of inference as rearrangements of one another's propositions (without the bracketed hints shown below).

Deduction.	Induction.	Hypothesis.
Rule: All the beans from this bag are white. *Case:* These beans are from this bag. ∴*Result:* These beans are white.	*Case:* These beans are [randomly selected] from this bag. *Result:* These beans are white. ∴*Rule:* All the beans from this bag are white.	*Rule:* All the beans from this bag are white. *Result:* These beans [oddly] are white. ∴*Case:* These beans are from this bag.

Peirce long treated abduction in terms of induction from characters or traits (weighed, not counted like objects), explicitly so in his influential 1883 "A Theory of Probable Inference", in which he returns to involving probability in the hypothetical conclusion.[25] Like "Deduction, Induction, and Hypothesis" in 1878, it was widely read (see the historical books on statistics by Stephen Stigler), unlike his later amendments of his conception of abduction. Today abduction remains most commonly understood as induction from characters and extension of a known rule to cover unexplained circumstances.

In 1902 Peirce wrote that he now regarded the syllogistical forms and the doctrine of extension and comprehension (i.e., objects and characters as referenced by terms), as being less fundamental than he had earlier thought.[26] In 1903 he offered the following form for abduction:[2]

> The surprising fact, C, is observed;
>
> > But if A were true, C would be a matter of course,
> >
> > Hence, there is reason to suspect that A is true.

The hypothesis is framed, but not asserted, in a premise, then asserted as rationally suspectable in the conclusion. Thus, as in the earlier categorical syllogistic form, the conclusion is formulated from some premise(s). But all the same the hypothesis consists more clearly than ever in a new or outside idea beyond what is known or observed. Induction in a sense goes beyond observations already reported in the premises, but it merely amplifies ideas already known to represent occurrences, or tests an idea supplied by hypothesis; either way it requires previous abductions in order to get such ideas in the first place. Induction seeks facts to test a hypothesis; abduction seeks a hypothesis to account for facts.

Note that the hypothesis ("A") could be of a rule. It need not even be a rule strictly necessitating the surprising observation ("C"), which needs to follow only as a "matter of course"; or the "course" itself could amount to some known rule, merely alluded to, and also not necessarily a rule of strict necessity. In the same year, Peirce wrote that reaching a hypothesis may involve placing a surprising observation under either a newly hypothesized rule or a hypothesized combination of a known rule with a peculiar state of facts, so that the phenomenon would be not surprising but instead either necessarily implied or at least likely.[24]

Peirce did not remain quite convinced about any such form as the categorical syllogistic form or the 1903 form. In 1911, he wrote, "I do not, at present, feel quite convinced that any logical form can be assigned that will cover all

"Retroductions". For what I mean by a Retroduction is simply a conjecture which arises in the mind."[3]

Peirce came over the years to divide (philosophical) logic into three departments:

1. Stechiology or speculative grammar, on the conditions for meaningfulness of signs and on classification of signs (semblances, symptoms, symbols, etc.) and of their combinations.
2. Logical critic, the critique of arguments in their distinct modes (deduction, induction, abduction).
3. Methodeutic or speculative rhetoric, on methods of inquiry in its coordinated modes.

Peirce had, from the start, seen the modes of inference as being coordinated together in scientific inquiry and, by the 1900s, held that hypothetical inference in particular is inadequately treated at the level of critique of arguments. To increase the assurance of a hypothetical conclusion, one needs to deduce implications about evidence to be found, predictions which induction can test through observation so as to evaluate the hypothesis. For Peirce that is the outline of the scientific method of inquiry and is studied in methodology of inquiry, a methodology including pragmatism or, as he later called it, pragmaticism, the clarification of ideas in terms of their conceivable implications regarding informed practice.

- At the critical level Peirce held that the hypothesis should economize explanation for plausibility in terms of the feasible and natural. In 1908 Peirce described this plausibility in some detail[13] . It involves not likeliness based on observations (which is instead the inductive evaluation of a hypothesis), but instead optimal simplicity in the sense of the "facile and natural", as by Galileo's natural light of reason and as distinct from "logical simplicity" (Peirce does not dismiss logical simplicity entirely but sees it in a subordinate role; taken to its logical extreme it would favor adding no explanation to the observation at all). Even a well-prepared mind guesses oftener wrong than right, but our guesses succeed better than random luck at reaching the truth or at least advancing the inquiry, and that indicates to Peirce that they are based in instinctive attunement to nature, an affinity between the mind's processes and the processes of the real, which would account for why appealingly "natural" guesses are the ones that oftenest (or least seldom) succeed; to which Peirce added the argument that such guesses are to be preferred since, without "a natural bent like nature's", people would have no hope of understanding nature. In 1910 Peirce made a three-way distinction between probability, verisimilitude, and plausibility, and defined plausibility with a normative "ought": "By plausibility, I mean the degree to which a theory ought to recommend itself to our belief independently of any kind of evidence other than our instinct urging us to regard it favorably."[27] The phrase "inference to the best explanation" (not used by Peirce but often applied to hypothetical inference) is not always understood as referring to the most simple and natural. However, in other senses of "best", such as "standing up best to tests", it is hard to know which is the best explanation to form, since one has not tested it yet.
- At the methodeutical level Peirce held that a hypothesis is judged and selected[17] for testing because it offers, via its trial, to economize and expedite the inquiry process itself toward new truths, first of all by being testable and also by further economies[4] , in terms of cost, value, and relationships among guesses (hypotheses). Here, considerations such as probability, absent from the treatment of abduction at the critical level, come into play. For examples:
  - Cost: A simple but low-odds guess, if low in cost to test for falsity, may belong first in line for testing, to get it out of the way. If surprisingly it stands up to tests, that is worth knowing early in the inquiry, which otherwise might have stayed long on a wrong though seemingly likelier track.
  - Value: A guess's objective probability recommonds it for trial, while subjective likelihood can be misleading.
  - Interrelationships: Guesses can be chosen for trial strategically, for which Peirce gave as example the game of Twenty Questions.[28]

In 1901 Peirce wrote, "There would be no logic in imposing rules, and saying that they ought to be followed, until it is made out that the purpose of hypothesis requires them."[29] In 1903 Peirce called pragmatism "the logic of abduction" and said that the pragmatic maxim gives the necessary and sufficient logical rule to abduction in general.[18] The pragmatic maxim is: "Consider what effects, that might conceivably have practical bearings, we conceive the object of our conception to have. Then, our conception of these effects is the whole of our conception of the object." It is a method for fruitful clarification of conceptions by equating the meaning of a conception with the conceivable practical implications of its object's conceived effects. Peirce held that that is precisely tailored to abduction's purpose in inquiry, the forming of an idea that could conceivably shape informed conduct. In various writings in the 1900s[4] [28] he said that the conduct of abduction (or retroduction) is governed by considerations of economy, belonging in particular to the economics of research. He regarded economics as a normative science whose analytic portion might be part of logical methodeutic.[30]

Norwood Russell Hanson, a philosopher of science, wanted to grasp a logic explaining how scientific discoveries take place. He used Peirce's notion of abduction for this.[31]

Further development of the concept can be found in Peter Lipton's *Inference to the Best Explanation* (Lipton, 1991).

Applications

Applications in artificial intelligence include fault diagnosis, belief revision, and automated planning. The most direct application of abduction is that of automatically detecting faults in systems: given a theory relating faults with their effects and a set of observed effects, abduction can be used to derive sets of faults that are likely to be the cause of the problem.

Abduction can also be used to model automated planning.[32] Given a logical theory relating action occurrences with their effects (for example, a formula of the event calculus), the problem of finding a plan for reaching a state can be modeled as the problem of abducting a set of literals implying that the final state is the goal state.

In intelligence analysis, Analysis of Competing Hypotheses and Bayesian networks, probabilistic abductive reasoning is used extensively. Similarly in medical diagnosis and legal reasoning, the same methods are being used, although there have been many examples of errors, especially caused by the base rate fallacy and the prosecutor's fallacy.

Belief revision, the process of adapting beliefs in view of new information, is another field in which abduction has been applied. The main problem of belief revision is that the new information may be inconsistent with the corpus of beliefs, while the result of the incorporation cannot be inconsistent. This process can be done by the use of abduction: once an explanation for the observation has been found, integrating it does not generate inconsistency. This use of abduction is not straightforward, as adding propositional formulae to other propositional formulae can only make inconsistencies worse. Instead, abduction is done at the level of the ordering of preference of the possible worlds. Preference models use fuzzy logic or utility models.

In the philosophy of science, abduction has been the key inference method to support scientific realism, and much of the debate about scientific realism is focused on whether abduction is an acceptable method of inference.

In historical linguistics, abduction during language acquisition is often taken to be an essential part of processes of language change such as reanalysis and analogy.[33]

In anthropology, Alfred Gell in his influential book *Art and Agency* defined abduction, (after Eco[34]) as “a case of synthetic inference 'where we find some very curious circumstances, which would be explained by the supposition that it was a case of some general rule, and thereupon adopt that supposition”.[35] Gell criticizes existing 'anthropological' studies of art, for being too preoccupied with aesthetic value and not preoccupied enough with the central anthropological concern of uncovering 'social relationships' specifically the social contexts in which artworks are produced, circulated, and received.[36] Abduction is used as the basis of one gets from art to agency in the sense of a theory of how works of art can inspire a *sensus communis,* or the commonly-held views that a characteristic of a given society because they are shared by everyone in that society.[37] The question Gell asks in the book is, ‘how does initially to ‘speak’ to people?’ He answers by saying that “No reasonable person could suppose that art-like relations between people and things do not involve at least some form of semiosis.”[35] However, he rejects any intimation that semiosis can be thought of as a language because then he would have to admit to some pre-established existence of the *sensus communis* that he wants to claim only emerges afterward out of art.

Abduction is the answer to this conundrum because the tentative nature of the abduction concept (Pierce likened it to guessing) means that not only can it operate outside of any pre-existing framework, but moreover, it can actually intimate the existence of a framework. As Gell reasons in his analysis, the physical existence of the artwork prompts the viewer to perform an abduction that imbues the artwork with intentionality. A statue of a goddess, for example, in some senses actually becomes the goddess in the mind of the beholder; and represents not only the form of the deity but also her intentions (which are adduced from the feeling of her very presence). Therefore through abduction, Gell claims that art can have the kind of agency that plants the seeds that grow into cultural myths. The power of agency is the power to motivate actions and inspire ultimately the shared understanding that characterizes any given society.[37]

See also

- Analogy
- Analysis of Competing Hypotheses
- Charles Sanders Peirce
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- Deductive reasoning
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- Sherlock Holmes
- Sign relation

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Notes

[1] Peirce, C. S.

- "On the Logic of drawing History from Ancient Documents especially from Testimonies" (1901), *Collected Papers* v. 7, paragraph 219.
- "PAP" ["Prolegomena to an Apology for Pragmatism"], MS 293 c. 1906, *New Elements of Mathematics* v. 4, pp. 319-320.
- A Letter to F. A. Woods (1913), *Collected Papers* v. 8, paragraphs 385-388.

(See under " Abduction (http://www.helsinki.fi/science/commens/terms/abduction.html)" and " Retroduction (http://www.helsinki.fi/science/commens/terms/retroduction.html)" at *Commens Dictionary of Peirce's Terms*.

[2] Peirce, C. S. (1903), Harvard lectures on pragmatism, *Collected Papers* v. 5, paragraphs 188–189 (http://www.textlog.de/7664-2.html).

[3] A Letter to J. H. Kehler (1911), *New Elements of Mathemaatics* v. 3, pp. 203–4, see under " Retroduction (http://www.helsinki.fi/science/commens/terms/retroduction.html)" at *Commens Dictionary of Peirce's Terms*.

[4] Peirce, C.S. (1902), application to the Carnegie Institution, see MS L75.329-330, from Draft D (http://www.cspeirce.com/menu/library/bycsp/l75/ver1/l75v1-08.htm#m27) of Memoir 27:

> Consequently, to discover is simply to expedite an event that would occur sooner or later, if we had not troubled ourselves to make the discovery. Consequently, the art of discovery is purely a question of economics. The economics of research is, so far as logic is concerned, the leading doctrine with reference to the art of discovery. Consequently, the conduct of abduction, which is chiefly a question of heuretic and is the first question of heuretic, is to be governed by economical considerations.

[5] For examples, see " Abductive Inference in Reasoning and Perception (http://www.cse.ohio-state.edu/lair/Projects/Abduction/abduction.html)", John R. Josephson, Laboratory for Artificial Intelligence Research, Ohio State University, and *Abduction, Reason, and Science. Processes of Discovery and Explanation* by Lorenzo Magnani (Kluwer Academic/Plenum Publishers, New York, 2001).

[6] Peirce Ms. 692, quoted in Sebeok, T. (1981) "You Know My Method." In Sebeok, T. "The Play of Musement." Bloomington, IA: Indiana. P 24

[7] Peirce Ms. 696, quoted in Sebeok, T. (1981) "You Know My Method." In Sebeok, T. "The Play of Musement." Bloomington, IA: Indiana. P 31

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[11] Popper, Karl (2002), *Conjectures and Refutations: The Growth of Scientific Knowledge*, London, UK: Routledge. p 536

[12] See Santaella, Lucia (1997) "The Development of Peirce's Three Types of Reasoning: Abduction, Deduction, and Induction", 6th Congress of the IASS. Eprint (http://www.pucsp.br/~lbraga/epap_peir1.htm).

[13] Peirce, C. S. (1908), "A Neglected Argument for the Reality of God", *Hibbert Journal* v. 7, pp. 90–112. See both part III and part IV. Reprinted, including originally unpublished portion, in *Collected Papers* v. 6, paragraphs 452–85, *Essential Peirce* v. 2, pp. 434–50, and elsewhere.

[14] Peirce used the term "intuition" not in the sense of an instinctive or anyway half-conscious inference as people often do currently. Instead he used "intuition" usually in the sense of a cognition devoid of logical determination by previous cognitions. He said, "We have no power of Intuition" in that sense. See his "Some Consequences of Four Incapacities" (1868), Eprint (http://www.peirce.org/writings/p27.html).

[15] For a relevant discussion of Peirce and the aims of abductive inference, see McKaughan, Daniel J. (2008), "From Ugly Duckling to Swan: C. S. Peirce, Abduction, and the Pursuit of Scientific Theories", *Transactions of the Charles S. Peirce Society*, v. 44, no. 3 (summer), 446–468.

[16] Peirce means "conceivable" very broadly. See *Collected Papers* v. 5, paragraph 196, or *Essential Peirce* v. 2, p. 235, "Pragmatism as the Logic of Abduction" (Lecture VII of the 1903 Harvard lectures on pragmatism):

It allows any flight of imagination, provided this imagination ultimately alights upon a possible practical effect; and thus many hypotheses may seem at first glance to be excluded by the pragmatical maxim that are not really so excluded.

[17] Peirce, C. S., Carnegie Application (L75, 1902, *New Elements of Mathematics* v. 4, pp. 37–38. See under " Abduction (http://www.helsinki.fi/science/commens/terms/abduction.html)" at the *Commens Dictionary of Peirce's Terms*:

Methodeutic has a special interest in Abduction, or the inference which starts a scientific hypothesis. For it is not sufficient that a hypothesis should be a justifiable one. Any hypothesis which explains the facts is justified critically. But among justifiable hypotheses we have to select that one which is suitable for being tested by experiment.

[18] Peirce, "Pragmatism as the Logic of Abduction" (Lecture VII of the 1903 Harvard lectures on pragmatism), see parts III and IV. Published in part in *Collected Papers* v. 5, paragraphs 180–212 (see 196–200, Eprint (http://www.textlog.de/7663.html) and in full in *Essential Peirce* v. 2, pp. 226–241 (see sections III and IV).

.... What is good abduction? What should an explanatory hypothesis be to be worthy to rank as a hypothesis? Of course, it must explain the facts. But what other conditions ought it to fulfill to be good? .... Any hypothesis, therefore, may be admissible, in the absence of any special reasons to the contrary, provided it be capable of experimental verification, and only insofar as it is capable of such verification. This is approximately the doctrine of pragmatism.

[19] Peirce, A Letter to Paul Carus circa 1910, *Collected Papers* v. 8, paragraphs 227–228. See under " Hypothesis (http://www.helsinki.fi/science/commens/terms/hypothesis.html)" at the *Commens Dictionary of Peirce's Terms*.

[20] (1867), "On the Natural Classification of Arguments", *Proceedings of the American Academy of Arts and Sciences* v. 7, pp. 261–287. Presented April 9, 1867. See especially starting at p. 284 (http://books.google.com/books?id=nG8UAAAAYAAJ&pg=PA284) in Part III §1. Reprinted in *Collected Papers v. 2, paragraphs 461–516 and* Writings *v. 2, pp. 23–49.*

[21] Peirce, C. S. (1878), "Deduction, Induction, and Hypothesis", *Popular Science Monthly*, v. 13, pp. 470–82, see 472 (http://books.google.com/books?id=u8sWAQAAIAAJ&jtp=472). *Collected Papers* 2.619–44, see 623.

[22] A letter to Langley, 1900, published in *Historical Perspectives on Peirce's Logic of Science*. See excerpts under " Abduction (http://www.helsinki.fi/science/commens/terms/abduction.html)" at the *Commens Dictionary of Peirce's Terms*.

[23] "A Syllabus of Certain Topics of Logic'" (1903 manuscript), *Essential Peirce* v. 2, see p. 287. See under " Abduction (http://www.helsinki.fi/science/commens/terms/abduction.html)" at the *Commens Dictionary of Peirce's Terms*.

[24] Peirce, C. S., "A Syllabus of Certain Topics of Logic" (1903), *Essential Peirce* v. 2, p. 287:

The mind seeks to bring the facts, as modified by the new discovery, into order; that is, to form a general conception embracing them. In some cases, it does this by an act of *generalization*. In other cases, no new law is suggested, but only a peculiar state of facts that will "explain" the surprising phenomenon; and a law already known is recognized as applicable to the suggested hypothesis, so that the phenomenon, under that assumption, would not be surprising, but quite likely, or even would be a necessary result. This synthesis suggesting a new conception or hypothesis, is the Abduction.

[25] Peirce, C. S. (1883), "A Theory of Probable Inference" in *Studies in Logic*).

[26] In Peirce, C. S., 'Minute Logic' circa 1902, *Collected Papers* v. 2, paragraph 102. See under " Abduction (http://www.helsinki.fi/science/commens/terms/abduction.html)" at *Commens Dictionary of Peirce's Terms*.

[27] Peirce, A Letter to Paul Carus 1910, *Collected Papers* v. 8, see paragraph 223.

[28] Peirce, "On the Logic of Drawing Ancient History from Documents", *Essential Peirce* v. 2, see pp. 107–9. On Twenty Questions, p. 109:

Thus, twenty skillful hypotheses will ascertain what 200,000 stupid ones might fail to do.

[29] Peirce, "On the Logic of drawing History from Ancient Documents", 1901 manuscript, *Collected Papers* v. 7, paragraphs 164–231, see 202, reprinted in *Essential Peirce* v. 2, pp. 75–114, see 95. See under " Abduction (http://www.helsinki.fi/science/commens/terms/abduction.html)" at *Commens Dictionary of Peirce's Terms*.

[30] Peirce, Carnegie application, L75 (1902), Memoir 28: "On the Economics of Research", scroll down to Draft E. Eprint (http://www.cspeirce.com/menu/library/bycsp/l75/ver1/l75v1-08.htm#m28).

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[43] http://www.pucsp.br/~lbraga/epap_peir1.htm
[44] http://www.creative-wisdom.com/pub/Peirce/Logic_of_EDA.html

External links

- " Abductive Inference in Reasoning and Perception (http://www.cse.ohio-state.edu/lair/Projects/Abduction/abduction.html)", John R. Josephson, Laboratory for Artificial Intelligence Research, Ohio State University.
- " Deduction, Induction, and Abduction (http://plato.stanford.edu/entries/peirce/#dia)", Chapter 3 in article " Charles Sanders Peirce (http://plato.stanford.edu/entries/peirce/)" by Robert Burch, 2001 and 2006, in the Stanford Encyclopedia of Philosophy (http://plato.stanford.edu/).
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- Commens Dictionary of Peirce's Terms (http://www.helsinki.fi/science/commens/dictionary.html), Mats Bergman and Sami Paavola, editors, Helsinki U. Peirce's own definitions, often many per term across the decades. There, see "Hypothesis [as a form of reasoning]", "Abduction", "Retroduction", and "Presumption [as a form of reasoning]".

Ability

Ability may be:

- Aptitude
- Intelligence
- Skill

Ability may also refer to:

- Ability score, in role-playing games
- Ability Plus Software, makers of the office suite Ability Office
- Ability grouping
- ABILITY Magazine
- Ability Magazine

Action theory (philosophy)

Action theory is an area in philosophy concerned with theories about the processes causing intentional (willful) human bodily movements of more or less complex kind. This area of thought has attracted the strong interest of philosophers ever since Aristotle's *Nicomachean Ethics* (Third Book). With the advent of psychology and later neuroscience, many theories of action are now subject to empirical testing.

Philosophical action theory, or the 'philosophy of action', should not be confused with sociological theories of social action, such as the action theory established by Talcott Parsons.

What is left over if I subtract the fact that my arm goes up from the fact that I raise my arm?

Ludwig Wittgenstein, *Philosophical Investigations* §621

Overview

Basic action theory typically describes action as behavior caused by an *agent* in a particular *situation*. The agent's *desires* and *beliefs* (e.g. my wanting a glass of water and believing the clear liquid in the cup in front of me is water) lead to bodily behavior (e.g. reaching over for the glass). In the simple theory (see Donald Davidson), the desire and belief jointly cause the action. Michael Bratman has raised problems for such a view and argued that we should take the concept of intention as basic and not analyzable into beliefs and desires.

In some theories a desire plus a belief about the means of satisfying that desire are always what is behind an action. Agents aim, in acting, to maximize the satisfaction of their desires. Such a theory of prospective rationality underlies much of economics and other social sciences within the more sophisticated framework of Rational Choice. However, many theories of action argue that rationality extends far beyond calculating the best means to achieve one's ends. For instance, a belief that I ought to do X, in some theories, can directly cause me to do X without my having to want to do X (i.e. have a desire to do X). Rationality, in such theories, also involves responding correctly to the reasons an agent perceives, not just acting on wants.

While action theorists generally employ the language of causality in their theories of what the nature of action is, the issue of what causal determination comes to has been central to controversies about the nature of free will.

Conceptual discussions also revolve around a precise definition of action in philosophy. Scholars may disagree on which bodily movements fall under this category, e.g. whether thinking should be analysed as action, and how complex actions involving several steps to be taken and diverse intended consequences are to be summarised or decomposed.

Discussion

For example, throwing a ball is an instance of action; it involves an intention, a goal, and a bodily movement guided by the agent. On the other hand, catching a cold is not considered an action because it is something which happens *to* a person, not something done *by* one. Generally an agent doesn't intend to catch a cold or engage in bodily movement to do so (though we might be able to conceive of such a case). Other events are less clearly defined as actions or not. For instance, distractedly drumming ones fingers on the table seems to fall somewhere in the middle. Deciding to do something might be considered a mental action by some. However, others think it is not an action unless the decision is carried out. Unsuccessfully trying to do something might also not be considered an action for similar reasons (for e.g. lack of bodily movement). It is contentious whether believing, intending, and thinking are actions since they are mental events.

Some would prefer to define actions as requiring bodily movement (see behaviorism). The side effects of actions are considered by some to be part of the action; in an example from Anscombe's manuscript Intention, pumping water can also be an instance of poisoning the inhabitants. This introduces a moral dimension to the discussion (see also Moral agency). If the poisoned water resulted in a death, that death might be considered part of the action of the agent that pumped the water. Whether a side effect is considered part of an action is especially unclear in cases in which the agent isn't aware of the possible side effects. For example, an agent that accidentally cures a person by administering a poison he was intending to kill him with.

A primary concern of the philosophy of action is to analyze the nature of actions and distinguish them from similar phenomena. Other concerns include individuating actions, explaining the relationship between actions and their effects, explaining how an action is related to the beliefs and desires which cause and/or justify it (see practical reason), as well as examining the nature of agency. A primary concern is the nature of free will and whether actions are determined by the mental states that precede them (see determinism). Some philosophers (e.g. Donald Davidson) have argued that the mental states the agent invokes as justifying his action are physical states that cause the action. Problems have been raised for this view because the mental states seem to be reduced to mere physical causes. Their mental properties don't seem to be doing any work. If the reasons an agent cites as justifying his action, however, are not the cause of the action, they must explain the action in some other way or be causally impotent.

Scholars of action theory

- Thomas Aquinas
- Hannah Arendt
- Robert Audi
- G. E. M. Anscombe
- Aristotle
- Jonathan Bennett
- Michael Bratman
- David Charles
- August Cieszkowski
- Arthur Collins
- Jonathan Dancy
- Donald Davidson
- William H. Dray
- Fred Dretske
- Ignacio Ellacuria
- John Martin Fischer
- Harry Frankfurt
- Carl Ginet
- Alvin I. Goldman
- Jürgen Habermas
- Hegel
- Carl Hempel
- Rosalind Hursthouse
- David Hume
- Jennifer Hornsby
- John Hyman
- Hans Joas
- Robert Kane
- Anthony Kenny
- Jaegwon Kim
- Christine Korsgaard
- Loet Leydesdorff
- John McDowell
- Alfred R. Mele
- Ludwig von Mises
- Thomas Nagel
- Timothy O'Connor
- Brian O'Shaughnessy
- Joseph Raz
- Thomas Reid
- Paul Ricoeur
- John Searle
- Wilfrid Sellars
- Michael Smith
- Galen Strawson
- Charles Taylor
- Richard Taylor
- Irving Thalberg
- Michael Thompson
- Judith Jarvis Thomson
- David Velleman
- Candace Vogler
- R. Jay Wallace
- Gary Watson
- George Wilson
- Georg Henrik von Wright
- Ludwig Wittgenstein
- Max Weber
- Xavier Zubiri

See also

- Enactivism
- Praxeology
- Practical reason

Further reading

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External links

- Action [1] entry in the *Stanford Encyclopedia of Philosophy*

http://philosophyofaction.com/

References

[1] http://plato.stanford.edu/entries/action

Adolescence

Adolescence (from Latin: *adolescere* meaning "to grow up")[1] is a transitional stage of physical and mental human development generally occurring between puberty and legal adulthood (age of majority),[1] but largely characterized as beginning and ending with the teenage stage.[2] [3] [4] According to Erik Erikson's stages of human development, for example, a young adult is generally a person between the ages of 20 and 40, whereas an adolescent is a person between the ages of 13 and 19.[] [] Historically, puberty has been heavily associated with teenagers and the onset of adolescent development.[5] [6] However, the start of puberty has had somewhat of an increase in preadolescence (particularly females, as seen with early and precocious puberty), and adolescence has had an occasional extension beyond the teenage years (typically males) compared to previous generations. These changes have made it more difficult to rigidly define the time frame in which adolescence occurs.[7] [8] [9] [10]

The end of adolescence and the beginning of adulthood varies by country and by function, and furthermore even within a single nation-state or culture there can be different ages at which an individual is considered to be (chronologically and legally) mature enough to be entrusted by society with certain tasks. Such milestones include, but are not limited to, driving a vehicle, having legal sexual relations, serving in the armed forces or on a jury, purchasing and drinking alcohol, voting, entering into contracts, completing certain levels of education, and marrying.

Adolescence is usually accompanied by an increased independence allowed by the parents or legal guardians and less supervision, contrary to the preadolescence stage.

History

In many societies, adolescence was not recognized as a phase of life. Most societies simply distinguished between childhood and adulthood. Stanley Hall is generally credited with "discovering" adolescence with his 1904 study "Adolescence" in which he describes the developmental phase now recognized as adolescence. Hall attributed the new stage to social changes at the turn of the 20th century. Child labor laws kept individuals under 16 out of the work force, and universal education laws kept them in secondary school, thus prolonging the period of dependence — a dependence that allowed them to address psychological tasks they might have ignored when they took on adult roles straight out of childhood.[11]

Puberty


Upper body of teenage boy. The structure has changed to resemble an adult form.

Puberty is a period of several years in which rapid physical growth and psychological changes occur, culminating in sexual maturity. The average onset of puberty is at 10 for girls and age 12 for boys.[12] Every person's individual timetable for puberty is influenced primarily by heredity, although environmental factors, such as diet and exercise, also exert some influence.[12] [13] [14] These factors can also contribute to precocious puberty and delayed puberty.[] [14]

Puberty begins with a surge in hormone production, which in turn causes a number of physical changes.[12] It is also the stage of life in which a child develops secondary sex characteristics (for example, a deeper voice and larger adam's apple in boys, and development of breasts and more curved and prominent hips in girls) as his or her hormonal balance shifts strongly towards an adult state. This is triggered by the pituitary gland, which secretes a surge of hormonal agents into the blood stream, initiating a chain reaction. The male and female gonads are subsequently activated, which puts them into a state of rapid growth and development; the triggered gonads now commence the mass production of the necessary chemicals. The testes primarily release testosterone, and the ovaries predominantly dispense estrogen. The production of these hormones increases gradually until sexual maturation is met. Some boys may develop gynecomastia due to an imbalance of sex hormones, tissue responsiveness or obesity.[15] [16] Put simply, puberty is the time when a child's body starts changing into an adult's body.[12]

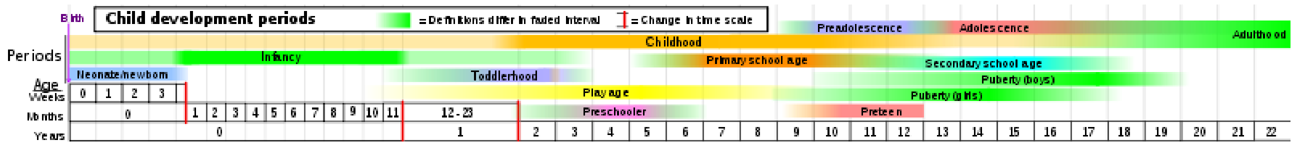
Facial hair in males normally appears in a specific order during puberty: The first facial hair to appear tends to grow at the corners of the upper lip, typically between 14 to 16 years of age.[17] [18] It then spreads to form a moustache over the entire upper lip. This is followed by the appearance of hair on the upper part of the cheeks, and the area under the lower lip.[] The hair eventually spreads to the sides and lower border of the chin, and the rest of the lower face to form a full beard.[] As with most human biological processes, this specific order may vary among some individuals. Facial hair is often present in late adolescence, around ages 17 and 18, but may not appear until significantly later.[] [19] Some men do not develop full facial hair for 10 years after puberty.[] Facial hair will continue to get coarser, darker and thicker for another 2–4 years after puberty.[]

The major landmark of puberty for males is the first ejaculation, which occurs, on average, at age 13.[20] For females, it is menarche, the onset of menstruation, which occurs, on average, between ages 12 and 13.[13] The age of menarche is influenced by heredity, but a girl's diet and lifestyle contribute as well.[13] Regardless of genes, a girl must have certain proportion of body fat to attain menarche.[13] Consequently, girls who have a high-fat diet and who are not physically active begin menstruating earlier, on average, than girls whose diet contains less fat and whose activities involve fat reducing exercise (e.g. ballet and gymnastics).[13] [14] Girls who experience malnutrition or are in societies in which children are expected to perform physical labor also begin menstruating at later ages.[13]

The timing of puberty can have important psychological and social consequences. Early maturing boys are usually taller and stronger than their friends.[21] They have the advantage in capturing the attention of potential partners and in becoming hand-picked for sports. Pubescent boys often tend to have a good body image, are more confident, secure, and more independent.[22] Late maturing boys can be less confident because of poor body image when comparing themselves to already developed friends and peers. However, early puberty is not always positive for boys; early sexual maturation in boys can be accompanied by increased aggressiveness due to the surge of hormones that affect them.[22] Because they appear older than their peers, pubescent boys may face increased social pressure to conform to adult norms; society may view them as more emotionally advanced, despite the fact that their cognitive and social development may lag behind their appearance.[22] Studies have shown that early maturing boys are more likely to be sexually active and are more likely to participate in risky behaviors.[23]

For girls, early maturation can sometimes lead to increased self-consciousness, though a typical aspect in maturing females.[24] Because of their bodies developing in advance, pubescent girls can become more insecure.[] Consequently, girls that reach sexual maturation early are more likely than their peers to develop eating disorders. Nearly half of all American high school girls' diet is to lose weight.[] In addition, girls may have to deal with sexual advances from older boys before they are emotionally and mentally mature.[25] In addition to having earlier sexual experiences and more unwanted pregnancies than late maturing girls, early maturing girls are more exposed to alcohol and drug abuse.[26] Those who have had such experiences tend to perform less well in school than their "inexperienced" age peers.[27]

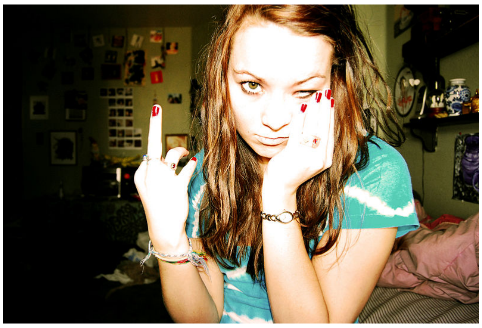
Girls have usually reached full physical development by ages 15–17,[28] [29] [30] while boys usually complete puberty by ages 16–18.[] [29] [31] Any increase in height beyond these ages is uncommon. Girls attain reproductive maturity about 4 years after the first physical changes of puberty appear.[30] In contrast, boys accelerate more slowly but continue to grow for about 6 years after the first visible pubertal changes.[22] [31] Teenage and early adult males may continue to gain natural muscle growth even after puberty.[22]



Approximate outline of development periods in child and teenager development. Adolescence is marked in red at top right.

Psychology

Adolescence is characterized by a number of cognitive, emotional, physical and attitudinal changes, which can be a cause of conflict on one hand and positive personality development on the other.


Expressed hostile attitude of a teenage girl.

The home environment and parents are still important for the behaviors and choices of adolescents.[32] Adolescents who have a good relationship with their parents are less likely to engage in various risk behaviors, such as smoking, drinking, fighting, and/or sexual intercourse.[32] In conflict with their parents, adolescents are more flexible than younger children, but more hostile and rigid compared to adults. The topics of conflicts between adolescents and their parents are often about the extent to which parents can control and supervise the adolescent, for instance conflicts about chores, schoolwork, curfew, and the adolescent's right to privacy.[33]

For the first time in their lives adolescents may start to view their friends, their peer group, as more important and influential than their parents or guardians.[34] Peer groups offer its members the opportunity to develop various social skills, such as empathy, sharing and leadership. Peer groups can have positive influences on an individual, for instance on academic motivation and performance, but they can also have negative influences and lead to an increase in experimentation with drugs, drinking, vandalism, and stealing.[35] Susceptibility to peer pressure increases during early adolescence, peaks around age 14, and declines thereafter.[36]

In the search for a unique social identity for themselves, adolescents are frequently confused about what is 'right' and what is 'wrong.' G. Stanley Hall denoted this period as one of "Storm and Stress" and, according to him, conflict at this developmental stage is normal and not unusual. Margaret Mead, on the other hand, attributed the behavior of adolescents to their culture and upbringing.[37]

Adolescence is also a time for rapid cognitive development.[38] Piaget describes adolescence as the stage of life in which the individual's thoughts start taking more of an abstract form and the egocentric thoughts decrease. This allows the individual to think and reason in a wider perspective.[39] A combination of behavioural and fMRI studies have demonstrated development of executive functions, that is, cognitive skills that enable the control and coordination of thoughts and behaviour, which are generally associated with the prefrontal cortex.[40] The thoughts, ideas and concepts developed at this period of life greatly influence one's future life, playing a major role in character and personality formation.[41]

Adolescent psychology is associated with notable changes in mood sometimes known as mood swings.

Positive psychology is sometimes brought up when addressing adolescent psychology as well. This approach towards adolescents refers to providing them with motivation to become socially acceptable and notable individuals, since many adolescents find themselves bored, indecisive and/or unmotivated.[42]

Struggles with adolescent identity and depression usually set in when an adolescent experiences a loss. The most important loss in their lives is the changing relationship between the adolescent and their parents. Adolescents may also experience strife in their relationships with friends. This may be due to the activities their friends take part in, such as smoking, which causes adolescents to feel as though participating in such activities themselves is likely essential to maintaining these friendships. Teen depression can be extremely intense at times because of physical and hormonal changes but emotional instability is part of adolescence. Their changing mind, body and relationships often present themselves as stressful and that change, they assume, is something to be feared.[43] Sleep deprivation has also been linked to adolescent depression, particularly in the teen years.[44]

Views of family relationships during adolescence are changing. The old view of family relationships during adolescence put an emphasis on conflict and disengagement and thought storm and stress was normal and even inevitable. However, the new view puts emphasis on transformation or relationships and maintenance of connectedness.

Sexuality

Adolescent sexuality refers to sexual feelings, behavior and development in adolescents and is a stage of human sexuality. Sexuality and sexual desire usually begins to intensify along with the onset of puberty. The expression of sexual desire among adolescents (or anyone, for that matter), might be influenced by family values and the culture and religion they have grown up in (or as a backlash to such), social engineering, social control, taboos, and other kinds of social mores.

Teenage couples at a fair in the American West.

In contemporary society, adolescents also face some risks as their sexuality begins to transform. Whilst some of these such as emotional distress (fear of abuse or exploitation) and sexually transmitted diseases (including HIV/AIDS) may not necessarily be inherent to adolescence, others such as pregnancy (through non-use or failure of contraceptives) are seen as social problems in most western societies. In terms of sexual identity, while all sexual orientations found in adults are also represented among adolescents, statistically the suicide rate amongst LGBT adolescents is up to four times higher than that of their heterosexual peers.[45]

According to anthropologist Margaret Mead and psychologist Albert Bandura, the turmoil found in adolescence in Western society has a cultural rather than a physical cause; they reported that societies where young women engaged in free sexual activity had no such adolescent turmoil.

In a 2008 study conducted by YouGov for Channel 4, 20% of 14–17-year-olds surveyed revealed that they had their first sexual experience at 13 or under.[46] Another study from 2002 found that those aged 15–44 reported that the average age of first sexual intercourse was 17.0 for males and 17.3 for females.[47]

The age of consent to sexual activity varies widely between international jurisdictions, ranging from 12 to 21 years.[48]

Culture

In commerce, this generation is seen as an important target. Mobile phones, contemporary popular music, movies, television programs, websites, sports, video games and clothes are heavily marketed and often popular amongst adolescents.

In the past (and still in some cultures) there were ceremonies that celebrated adulthood, typically occurring during adolescence. *Seijin shiki* (literally "adult ceremony") is a Japanese example of this. Upanayanam is a coming of age ceremony for males in the Hindu world. In Judaism, 13-year-old boys and 12-year-old girls become Bar or Bat Mitzvah, respectively, and often have a celebration to mark this coming of age. Among some denominations of Christianity, the rite or sacrament of Confirmation is received by adolescents and may be considered the time at which adolescents become members of the church in their own right (there is also a Confirmation ceremony in some Reform Jewish temples, although the bar or bat mitzvah ceremony appears to have precedence). In United States, girls will often have a "sweet sixteen" party to celebrate turning the aforementioned age, a tradition similar to the quinceañera in Latin culture. In modern western society, events such as getting your first driver's license, high school and later on college graduation and first career related job are thought of as being more significant markers in transition to adulthood.

Adolescents have also been an important factor in many movements for positive social change around the world. The popular history of adolescents participating in these movements may perhaps start with Joan of Arc, and extend to present times with popular youth activism, student activism, and other efforts to make the youth voice heard.

Legal issues, rights and privileges

Internationally, those who reach a certain age (often 18, though this varies) are legally considered to have reached the age of majority and are regarded as adults and are held to be responsible for their actions. People below this age are considered minors or children. A person below the age of majority may gain adult rights through legal emancipation.

Those who are under the age of consent, or legal responsibility, may be considered too young to be held accountable for criminal action. This is called *doli incapax* or the defense of infancy. The age of criminal responsibility varies from 7 in India to 18 in Belgium. After reaching the initial age, there may be levels of responsibility dictated by age and type of offense, and crimes committed by minors may be tried in a juvenile court.

The legal working age in Western countries is usually 14 to 16, depending on the number of hours and type of employment. In the United Kingdom and Canada, for example, young people between 14 and 16 can work at certain types of light work with some restrictions to allow for schooling; while youths over 16 can work full-time (excluding night work). Many countries also specify a minimum school leaving age, ranging from 10 to 18, at which a person is legally allowed to leave compulsory education.

The age of consent to sexual activity varies widely between jurisdictions, ranging from 13 to 21 years, the average age is 16.[49] In a 2008 study of 14 to 17-year-olds conducted by YouGov for Channel 4, it was revealed that one in three 15-year-olds were sexually active.[46]

Sexual intercourse with a person below the local age of consent is usually treated as the crime of statutory rape. Some jurisdictions allow an exemption where both partners are close in age; for example, a 16-year-old and an 18-year-old. The age at which people are allowed to marry also varies, from 17 in Yemen to 22 for males and 20 for females in China. In Western countries, people are typically allowed to marry at 18, although they are sometimes allowed to marry at a younger age with parental or court consent. In developing countries, the legal marriageable age does not always correspond with the age at which people actually marry; for example, the legal age for marriage in Ethiopia is 18 for both males and females, but in rural areas most girls are married by age 16.

In most democratic countries, a citizen is eligible to vote at 18. For example, in the United States, the Twenty-sixth amendment decreased the voting age from 21 to 18. In a minority of countries, the voting age is 17 (for example, Indonesia) or 16 (for example, Brazil). By contrast, some countries have a minimum voting age of 21 (for example, Singapore) whereas the minimum age in Uzbekistan is 25. Age of candidacy is the minimum age at which a person can legally qualify to hold certain elected government offices. In most countries, a person must be 18 or over to stand for elected office, but some countries such as the United States and Italy have further restrictions depending on the type of office.

A sign outside a sex shop reads "Must Be 18 To Enter" in Chapel Hill, North Carolina.

The sale of selected items such as cigarettes, alcohol, and videos with violent or pornographic content is also restricted by age in most countries. In the U.S, the minimum age to buy an R-rated movie, M-rated game or an album with a parental advisory label is 17 (in some states 18 or even 21). In practice, it is common that young people engage in underage smoking or drinking, and in some cultures this is tolerated to a certain degree. In the United States, teenagers are allowed to drive between 14–18 (each state sets its own minimum driving age of which a curfew may be imposed), in the US, adolescents 17 years of age can serve in the military. In Europe it is more common for the driving age to be higher (usually 18) while the drinking age is lower than that of the US (usually 16 or 18). In Canada, the drinking age is 18 in some areas and 19 in other areas. In Australia, universally the minimum drinking age is 18, unless a person is in a private residence or is under parental supervision in a licensed premises. The driving age varies from state to state but the more common system is a graduated system of "L plates" (a learning license that requires supervision from a licensed driver) from age 16, red "P plates" (probationary license) at 17, green "P plates" at 18 and finally a full license, i.e. for most people around the age of 20.

The legal gambling age also depends on the jurisdiction, although it is typically 18.

The minimum age for donating blood in the U.S is 17 although it may be 16 with parental permission in some states such as New York, New Jersey, and Pennsylvania.

Suitable age and discretion is a legal definition of maturity.[50]

A number of social scientists, including anthropologist Margaret Mead and sociologist Mike Males, have noted the contradictory treatment of laws affecting adolescents in the United States. As Males has noted, the US Supreme Court has, "explicitly ruled that policy-makers may impose adult responsibilities and punishments on individual youths as if they were adults at the same time laws and policies abrogate adolescents' rights en masse as if they were children."

The issue of youth activism affecting political, social, educational, and moral circumstances is of growing significance around the world. Youth-led organizations around the world have fought for social justice, the youth vote seeking to gain teenagers the right to vote, to secure more youth rights, and demanding better schools through student activism.

Since the advent of the Convention on the Rights of the Child in 1989 (children defined as under 18), almost every country (except the U.S. & Somalia) in the world has become voluntarily legally committed to advancing an anti-discriminatory stance towards young people of all ages. This is a legally binding document which secures youth participation throughout society while acting against unchecked child labor, child soldiers, child prostitution, and pornography.

See also

- Adolescent medicine
- Ephebophilia - a sexual preference in which an adult is primarily or exclusively sexually attracted to mid to late adolescents
- Fear of youth
- Images of young people
- Juvenile Delinquency
- Medical School
- Pedophilia (or paedophilia) - a psychiatric disorder in adults or late adolescents for whom prepubescent children are the primary or exclusive sexual object of their libido.
- Rite of passage
- Sex education
- Student voice
- Suitable age and discretion
- Teen Dating Violence
- Teen drama - (List of teen dramas)
- Teen film - (List of teen films)
- Teen idol
- Teen magazine
- Teen pop
- Timeline of children's rights in the United Kingdom
- Timeline of children's rights in the United States
- Youth
- Youth culture
- Youth voice
- Young worker safety and health

Human development and psychology

- Developmental psychology
- Educational psychology
- Erikson's stages of psychosocial development particularly stages 5 & 6
- Human development
- Kohlberg's stages of moral development particularly stage 3

Compare with

- Aging
- Peter Pan syndrome
- Young adult

Literature

- Tennessee Williams - a description of the emotional impact of puberty and adolescence is to be found in *The Resemblance Between a Violin and a Coffin*
- Jon Savage - a (pre)history of the development of the teenager is to be found in *Teenage* (Chatto and Windus, 2007)

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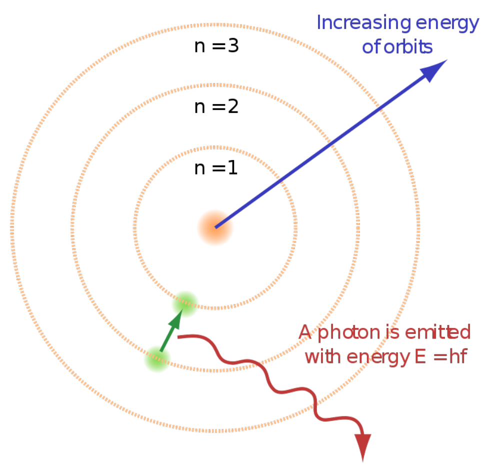
Analogy

Analogy (from Greek "ἀναλογία" – *analogia*, "proportion"[1] [2]) is a cognitive process of transferring information or meaning from a particular subject (the analogue or source) to another particular subject (the target), and a linguistic expression corresponding to such a process. In a narrower sense, analogy is an inference or an argument from one particular to another particular, as opposed to deduction, induction, and abduction, where at least one of the premises or the conclusion is general. The word *analogy* can also refer to the relation between the source and the target themselves, which is often, though not necessarily, a similarity, as in the biological notion of analogy.



Niels Bohr's model of the atom, though inaccurate, made an analogy between the atom and the solar system.

Analogy plays a significant role in problem solving, decision making, perception, memory, creativity, emotion, explanation and communication. It lies behind basic tasks such as the identification of places, objects and people, for example, in face perception and facial recognition systems. It has been argued that analogy is "the core of cognition".[3] Specific analogical language comprises exemplification, comparisons, metaphors, similes, allegories, and parables, but *not* metonymy. Phrases like *and so on*, *and the like*, *as if*, and the very word *like* also rely on an analogical understanding by the receiver of a message including them. Analogy is important not only in ordinary language and common sense (where proverbs and idioms give many examples of its application) but also in science, philosophy and the humanities. The concepts of association, comparison, correspondence, mathematical and morphological homology, homomorphism, iconicity, isomorphism, metaphor, resemblance, and similarity are closely related to analogy. In cognitive linguistics, the notion of conceptual metaphor may be equivalent to that of analogy.

Analogy has been studied and discussed since classical antiquity by philosophers, scientists and lawyers. The last few decades have shown a renewed interest in analogy, most notable in cognitive science.

Usage of the terms *source* and *target*

With respect to the terms *source* and *target* there are two distinct traditions of usage:

- The logical and mathematical tradition speaks of an *arrow*, *homomorphism*, *mapping*, or *morphism* from what is typically the more complex *domain* or *source* to what is typically the less complex *codomain* or *target*, using all of these words in the sense of mathematical category theory.
- The tradition that appears to be more common in cognitive psychology, literary theory, and specializations within philosophy outside of logic, speaks of a mapping from what is typically the more familiar area of experience, the *source*, to what is typically the more problematic area of experience, the *target*.

Models and theories

Identity of relation

In ancient Greek the word *αναλογια* (*analogia*) originally meant proportionality, in the mathematical sense, and it was indeed sometimes translated to Latin as *proportio*. From there analogy was understood as **identity of relation** between any two ordered pairs, whether of mathematical nature or not. Kant's *Critique of Judgment* held to this notion. Kant argued that there can be exactly the same relation between two completely different objects. The same notion of analogy was used in the US-based SAT tests, that included "analogy questions" in the form "A is to B as C is to *what*?" For example, "Hand is to palm as foot is to ____?" These questions were usually given in the Aristotelian format:

HAND : PALM : : FOOT : ____

While most competent English speakers will immediately give the right answer to the analogy question (*sole*), it is more difficult to identify and describe the exact relation that holds both between *hand* and *palm*, and between *foot* and *sole*. This relation is not apparent in some lexical definitions of *palm* and *sole*, where the former is defined as *the inner surface of the hand*, and the latter as *the underside of the foot*. Analogy and abstraction are different cognitive processes, and analogy is often an easier one.

Recently a computer algorithm has achieved human-level performance on multiple-choice analogy questions from the SAT test.[4] The algorithm measures the similarity of relations between pairs of words (e.g., the similarity between the pairs HAND:PALM and FOOT:SOLE) by statistical analysis of a large collection of text. It answers SAT questions by selecting the choice with the highest relational similarity.

Shared abstraction

In several cultures, the sun is the source of an analogy to God.

Greek philosophers such as Plato and Aristotle actually used a wider notion of analogy. They saw analogy as a **shared abstraction**.[5] Analogous objects did not share necessarily a relation, but also an idea, a pattern, a regularity, an attribute, an effect or a function. These authors also accepted that comparisons, metaphors and "images" (allegories) could be used as arguments, and sometimes they called them *analogies*. Analogies should also make those abstractions easier to understand and give confidence to the ones using them.

The Middle Ages saw an increased use and theorization of analogy. Roman lawyers had already used analogical reasoning and the Greek word *analogia*. Medieval lawyers distinguished *analogia legis* and *analogia iuris* (see below). In Islamic logic, analogical reasoning was used for the process of Qiyas in Islamic sharia law and fiqh jurisprudence. In Christian theology, analogical arguments were accepted in order to explain the attributes of God. Aquinas made a distinction between *equivocal*, *univocal* and *analogical* terms, the latter being those like *healthy* that have different but related meanings. Not only a person can be "healthy", but also the food that is good for health (see the contemporary distinction between polysemy and homonymy). Thomas Cajetan wrote an influential treatise on analogy. In all of these cases, the wide Platonic and Aristotelian notion of analogy was preserved. James Francis Ross in *Portraying Analogy* (1982), the first substantive examination of the topic since Cajetan's *De Nominum Analogia*, demonstrated that analogy is a systematic and universal feature of natural languages, with identifiable and law-like characteristics which explain how the meanings of words in a sentence are interdependent.

Special case of induction

On the contrary, Ibn Taymiyya,[6] [7] [8] Francis Bacon and later John Stuart Mill argued that analogy is simply **a special case of induction**.[5] In their view analogy is an inductive inference from common known attributes to another probable common attribute, which is known only about the source of the analogy, in the following form:

Premises

a is C, D, E, F, G

b is C, D, E, F

Conclusion

b is probably G.

Alternative conclusion

every C, D, E, F is probably G.

This view does not accept analogy as an autonomous mode of thought or inference, reducing it to induction. However, autonomous analogical arguments are still useful in science, philosophy and the humanities (see below), which makes this reduction philosophically uninteresting. Moreover, induction tries to achieve general conclusions, while analogy looks for particular ones.

Hidden deduction

The opposite move could also be tried, **reducing analogy to deduction**. It is argued that every analogical argument is partially superfluous and can be rendered as a deduction stating as a premise a (previously hidden) universal proposition which applied both to the source and the target. In this view, instead of an argument with the form:

Premises

a is analogous to *b*.

b is F.

Conclusion

a is plausibly F.

We should have:

Hidden universal premise

all Gs are plausibly Fs.

Hidden singular premise

a is G.

Conclusion

a is plausibly F.

This would mean that premises referring the source and the analogical relation are themselves superfluous. However, it is not always possible to find a plausibly true universal premise to replace the analogical premises.[9] And analogy is not only an argument, but also a distinct cognitive process.

Shared structure

According to Shelley (2003), the study of the coelacanth drew heavily on analogies from other fish.

Contemporary cognitive scientists use a wide notion of analogy, extensionally close to that of Plato and Aristotle, but framed by Gentner's (1983) **structure mapping theory**.[10] The same idea of mapping between source and target is used by conceptual metaphor and conceptual blending theorists. Structure mapping theory concerns both psychology and computer science. According to this view, analogy depends on the mapping or alignment of the elements of source and target. The mapping takes place not only between objects, but also between relations of objects and between relations of relations. The whole mapping yields the assignment of a predicate or a relation to the target. Structure mapping theory has been applied and has found considerable confirmation in psychology. It has had reasonable success in computer science and artificial intelligence (see below). Some studies extended the approach to specific subjects, such as metaphor and similarity.[11]

Keith Holyoak and Paul Thagard (1997) developed their **multiconstraint theory** within structure mapping theory. They defend that the "coherence" of an analogy depends on structural consistency, semantic similarity and purpose. Structural consistency is maximal when the analogy is an isomorphism, although lower levels are admitted. Similarity demands that the mapping connects similar elements and relations of source and target, at any level of abstraction. It is maximal when there are identical relations and when connected elements have many identical attributes. An analogy achieves its purpose insofar as it helps solve the problem at hand. The multiconstraint theory faces some difficulties when there are multiple sources, but these can be overcome.[5] Hummel and Holyoak (2005) recast the multiconstraint theory within a neural network architecture. A problem for the multiconstraint theory arises from its concept of similarity, which, in this respect, is not obviously different from analogy itself. Computer applications demand that there are some *identical* attributes or relations at some level of abstraction. Human analogy does not, or at least not apparently.

Mark T. Keane and Brayshaw (1988) developed their *Incremental Analogy Machine* (IAM) to include working memory constraints as well as structural, semantic and pragmatic constraints, so that a subset of the base analog is selected and mapping from base to target occurs in a serial manner.[12] [13] Empirical evidence shows that human analogical mapping performance is influenced by information presentation order.[14]

High-level perception

Douglas Hofstadter and his team[15] challenged the shared structure theory and mostly its applications in computer science. They argue that there is no line between perception, including high-level perception, and analogical thought. In fact, analogy occurs not only after, but also before and at the same time as high-level perception. In high-level perception, humans make representations by selecting relevant information from low-level stimuli. Perception is necessary for analogy, but analogy is also necessary for high-level perception. Chalmers et al. conclude that analogy ***is*** high-level perception. Forbus et al. (1998) claim that this is only a metaphor. It has been argued (Morrison and Dietrich 1995) that Hofstadter's and Gentner's groups do not defend opposite views, but are instead dealing with different aspects of analogy.

Analogy and Complexity

Antoine Cornuéjols[16] has presented analogy as a *principle of economy* and *computational complexity*.

Reasoning by analogy is a process of, from a given pair $(x,f(x))$, extrapolating the function f. In the standard modeling, analogical reasoning involves two "objects": the *source* and the *target*. The target is supposed to be incomplete and in need for a complete description using the source. The target has an existing part S_t and a missing part R_t. We assume that we can isolate a situation of the source S_s, which corresponds to a situation of target S_t, and the result of the source R_s, which correspond to the result of the target R_t. With B_s, the relation between S_s and R_s, we want B_t, the relation between S_t and R_t.

If the source and target are completely known:

Using Kolmogorov complexity $K(x)$, defined as the size of the smallest description of x and Solomonoff's approach to induction, Rissanen (89),[17] Wallace & Boulton (68) proposed the principle of Minimum description length. This principle leads to minimize the complexity $K(target|\ Source)$ of producing the target from the source.

This is unattractive in Artificial Intelligence, as it requires a computation over abstract Turing machines. Suppose that M_s and M_t are local theories of the source and the target, available to the observer. The best analogy between a source case a and target case is the analogy that minimizes:

$$K(M_s) + K(S_s|M_s) + K(B_s|M_s) + K(M_t|M_s) + K(S_t|M_t) + K(B_t|M_t) \text{ (1).}$$

If the target is completely unknown:

All models and descriptions M_s, M_t, B_s, S_s, and S_t leading to the minimization of:

$$K(M_s) + K(S_s|M_s) + K(B_s|M_s) + K(M_t|M_s) + K(S_t|M_t) \text{ (2)}$$

are also those who allow to obtain the relationship B_t, and thus the most satisfactory R_t for formula (1).

The analogical hypothesis, which solves an analogy between a source case and a target case, has two parts:

- Analogy, like induction, is a *principle of economy*. The best analogy between two cases is the one which minimizes the amount of information necessary for the derivation of the source from the target (1). Its most

fundamental measure is the computational complexity theory.
- When solving or completing a target case with a source case, the parameters which minimize (2) are postulated to minimize (1), and thus, produce the best response.

However, a *cognitive agent* may simply reduce the amount of information necessary for the interpretation of the source and the target, without taking into account the cost of data replication. So, it may prefer to the minimization of (2) the minimization of the following simplified formula:

$K(M_s) + K(B_s|M_s) + K(M_t|M_s)$ (3).

Applications and types

In language

Rhetoric

- An analogy can be a spoken or textual comparison between two words (or sets of words) to highlight some form of semantic similarity between them. Such analogies can be used to strengthen political and philosophical arguments, even when the semantic similarity is weak or non-existent (if crafted carefully for the audience). Analogies are sometimes used to persuade those that cannot detect the flawed or non-existent arguments.

Linguistics

- An analogy can be the linguistic process that reduces word forms perceived as irregular by remaking them in the shape of more common forms that are governed by rules. For example, the English verb *help* once had the preterite *holp* and the past participle *holpen*. These obsolete forms have been discarded and replaced by *helped* by the power of analogy (or by widened application of the productive Verb-*ed* rule.) This is called *leveling*. However, irregular forms can sometimes be created by analogy; one example is the American English past tense form of *dive*: *dove*, formed on analogy with words such as *drive*: *drove*.
- Neologisms can also be formed by analogy with existing words. A good example is *software*, formed by analogy with *hardware*; other analogous neologisms such as *firmware* and *vaporware* have followed. Another example is the humorous term *underwhelm*, formed by analogy with *overwhelm*.
- Analogy is often presented as an alternative mechanism to generative *rules* for explaining productive formation of structures such as words. Others argue that in fact they are the same mechanism, that rules are analogies that have become entrenched as standard parts of the linguistic system, whereas clearer cases of analogy have simply not (yet) done so (e.g. Langacker 1987.445–447). This view has obvious resonances with the current views of analogy in cognitive science which are discussed above.

In science

Analogues are often used in theoretical and applied sciences in the form of models or simulations which can be considered as strong analogies. Other much weaker analogies assist in understanding and describing functional behaviours of similar systems. For instance, an analogy commonly used in electronics textbooks compares electrical circuits to hydraulics. Another example is the analog ear based on electrical, electronic or mechanical devices.

Mathematics

Some types of analogies can have a precise mathematical formulation through the concept of isomorphism. In detail, this means that given two mathematical structures of the same type, an analogy between them can be thought of as a bijection between them which preserves some or all of the relevant structure. For example, $\mathbb{R}^2$ and $\mathbb{C}$ are isomorphic as vector spaces, but the complex numbers, $\mathbb{C}$, have more structure than $\mathbb{R}^2$ does – $\mathbb{C}$ is a field as well as a vector space.

Category theory takes the idea of mathematical analogy much further with the concept of functors. Given two categories C and D a functor F from C to D can be thought of as an analogy between C and D, because F has to map objects of C to objects of D and arrows of C to arrows of D in such a way that the compositional structure of the two categories is preserved. This is similar to the structure mapping theory of analogy of Dedre Gentner, in that it formalizes the idea of analogy as a function which satisfies certain conditions.

Artificial intelligence

See case-based reasoning.

Anatomy

In anatomy, two anatomical structures are considered to be *analogous* when they serve similar functions but are not evolutionarily related, such as the legs of vertebrates and the legs of insects. Analogous structures are the result of convergent evolution and should be contrasted with homologous structures.

Engineering

Often a physical prototype is built to model and represent some other physical object. For example, wind tunnels are used to test scale models of wings and aircraft, which act as an analog to full-size wings and aircraft.

For example, the MONIAC (an analog computer) used the flow of water in its pipes as an analog to the flow of money in an economy.

In normative matters

Morality

Analogical reasoning plays a very important part in morality. This may be in part because morality is supposed to be impartial and fair. If it is wrong to do something in a situation A, and situation B is analogous to A in all relevant features, then it is also wrong to perform that action in situation B. Moral particularism accepts analogical moral reasoning, rejecting both deduction and induction, since only the former can do without moral principles.

Law

In law, analogy is used to resolve issues on which there is no previous authority. A distinction has to be made between analogous reasoning from written law and analogy to precedent case law.

Analogies from codes and statutes

In civil law systems, where the preeminent source of law is legal codes and statutes, a lacuna (a gap) arises when a specific issue is not explicitly dealt with in written law. Judges will try to identify a provision whose purpose applies to the case at hand. That process can reach a high degree of sophistication, as judges sometimes not only look at a specific provision to fill lacunae (gaps), but at several provisions (from which an underlying purpose can be inferred) or at general principles of the law to identify the legislator's value judgement from which the analogy is drawn. Besides the not very frequent filling of lacunae, analogy is very commonly used between different provisions in order to achieve substantial coherence. Analogy from previous judicial decisions is also common, although these decisions are not binding authorities.

Analogies from precedent case law

By contrast, in common law systems, where precedent cases are the primary source of law, analogies to codes and statutes are rare (since those are not seen as a coherent system, but as incursions into the common law). Analogies are thus usually drawn from precedent cases: The judge finds that the facts of another case are similar to the one at hand to an extent that the analogous application of the rule established in the previous case is justified.

See also

- List of thinking-related topics
- Conceptual metaphor
- Conceptual blending
- False analogy
- Portal: thinking
- Metaphor
- Allegory

Notes

[1] ἀναλογία (http://www.perseus.tufts.edu/hopper/text?doc=Perseus:text:1999.04.0057:entry=a)nalogi/a), Henry George Liddell, Robert Scott, *A Greek-English Lexicon*, on Perseus Digital Library
[2] analogy (http://www.etymonline.com/index.php?term=analogy), Online Etymology Dictionary
[3] Hofstadter in Gentner et al. 2001.
[4] Turney 2006
[5] Shelley 2003
[6] Hallaq, Wael B. (1985–1986). "The Logic of Legal Reasoning in Religious and Non-Religious Cultures: The Case of Islamic Law and the Common Law". *Cleveland State Law Review* **34**: 79–96 [93–5]
[7] Ruth Mas (1998). "Qiyas: A Study in Islamic Logic" (http://www.colorado.edu/ReligiousStudies/faculty/mas/LOGIC.pdf). *Folia Orientalia* **34**: 113–128. ISSN 0015-5675. .
[8] John F. Sowa; Arun K. Majumdar (2003). "Analogical reasoning" (http://www.jfsowa.com/pubs/analog.htm). . Berlin: Springer-Verlag. ., pp. 16–36
[9] See Juthe 2005
[10] See Dedre Gentner et al. 2001
[11] See Gentner et al. 2001 and Gentner's publication page (http://groups.psych.northwestern.edu/gentner/publications2.htm).
[12] Keane, M.T. and Brayshaw, M. (1988). The Incremental Analogical Machine: a computational model of analogy. In D. Sleeman (Ed). European working session on learning. (pp.53–62). London: Pitman.
[13] Keane, M.T. Ledgeway; Duff, S (1994). "Constraints on analogical mapping: a comparison of three models". *Cognitive Science* **18**: 287–334.
[14] Keane, M.T. (1997). "What makes an analogy difficult? The effects of order and causal structure in analogical mapping". *Journal of Experimental Psychology: Learning, Memory and Cognition* **123**: 946–967.
[15] See Chalmers et al. 1991
[16] Cornuéjols, A. (1996). Analogie, principe d'économie et complexité algorithmique (http://www.lri.fr/~antoine/Papers/JFA96-final-osX.pdf). In *Actes des 11èmes Journées Françaises de l'Apprentissage*. Sète.
[17] Rissanen J. (1989) : *Stochastical Complexity and Statistical Inquiry*. World Scientific Publishing Company, 1989.

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External links

- *Dictionary of the History of Ideas:* (http://etext.lib.virginia.edu/cgi-local/DHI/dhi.cgi?id=dv1-09) Analogy in Early Greek Thought.
- *Dictionary of the History of Ideas*: (http://etext.lib.virginia.edu/cgi-local/DHI/dhi.cgi?id=dv1-10) Analogy in Patristic and Medieval Thought.
- *Stanford Encyclopedia of Philosophy*: (http://plato.stanford.edu/entries/analogy-medieval/) Medieval Theories of Analogy.
- Dedre Gentner's publications page (http://www.psych.northwestern.edu/psych/people/faculty/gentner/publications2.htm), most of them on analogy and available for download.
- Shawn Glynn’s publications page (http://www.coe.uga.edu/twa/), all on teaching with analogies and some available for download.
- Keith Holyoak's publications page (http://reasoninglab.psych.ucla.edu/KeithPublications.htm), many on analogy and available for download.
- Boicho Kokinov's publications page (http://nbu.bg/cogs/personal/kokinov/index.html), most of them on analogy and available for download.
- jMapper – Java Library for Analogy/Metaphor Generation (http://student.dei.uc.pt/~racosta/jmapper)

Argument

In logic, an **argument** is a set of one or more meaningful declarative sentences (or "propositions") known as the premises along with another meaningful declarative sentence (or "proposition") known as the conclusion. A deductive argument asserts that the truth of the conclusion is a logical consequence of the premises; an inductive argument asserts that the truth of the conclusion is supported by the premises. Deductive arguments are valid or invalid, and sound or not sound. An argument is valid if and only if the truth of the conclusion **is** a logical consequence of the premises and (consequently) its corresponding conditional is a necessary truth. A sound argument is a valid argument with true premises.

Each premise and the conclusion are only either true or false, i.e. are truth bearers. The sentences composing an argument are referred to as being either *true* or *false*, not as being *valid* or *invalid*; deductive arguments are referred to as being *valid* or *invalid*, not as being *true* or *false*. Some authors refer to the premises and conclusion using the terms *declarative sentence*, *statement*, *proposition*, *sentence*, or even *indicative utterance*. The reason for the variety is concern about the ontological significance of the terms, *proposition* in particular. Whichever term is used, each premise and the conclusion must be capable of being true or false and nothing else: they are truthbearers.

Formal and informal arguments

Informal arguments are studied in *informal logic*, are presented in ordinary language and are intended for everyday discourse. Conversely, formal arguments are studied in *formal logic* (historically called *symbolic logic*, more commonly referred to as *mathematical logic* today) and are expressed in a formal language. Informal logic may be said to emphasize the study of argumentation, whereas formal logic emphasizes implication and inference. Informal arguments are sometimes implicit. That is, the logical structure – the relationship of claims, premises, warrants, relations of implication, and conclusion – is not always spelled out and immediately visible and must sometimes be made explicit by analysis.

Deductive arguments

A *deductive argument* is one which, if valid, has a conclusion that is entailed by its premises. In other words, the truth of the conclusion is a logical consequence of the premises—if the premises are true, then the conclusion must be true. It would be self-contradictory to assert the premises and deny the conclusion, because the negation of the conclusion is contradictory to the truth of the premises.

Validity

Arguments may be either valid or invalid. If an argument is valid, and its premises are true, the conclusion must be true: a valid argument cannot have true premises and a false conclusion.

The validity of an argument depends, however, not on the actual truth or falsity of its premises and conclusions, but solely on whether or not the argument has a valid logical form. The validity of an argument is not a guarantee of the truth of its conclusion. A valid argument may have false premises and a false conclusion.

Logic seeks to discover the valid forms, the forms that make arguments valid arguments. An argument form is valid if and only if all arguments of that form are valid. Since the validity of an argument depends on its form, an argument can be shown to be invalid by showing that its form is invalid, and this can be done by giving another argument of the same form that has true premises but a false conclusion. In informal logic this is called a counter argument.

The form of argument can be shown by the use of symbols. For each argument form, there is a corresponding statement form, called a corresponding conditional, and an argument form is valid if and only its corresponding conditional is a logical truth. A statement form which is logically true is also said to be a valid statement form. A statement form is a logical truth if it is true under all interpretations. A statement form can be shown to be a logical truth by either (a) showing that it is a tautology or (b) by means of a proof procedure.

The *corresponding conditional*, of a valid argument is a necessary truth (true *in all possible worlds*) and so we might say that the conclusion necessarily follows from the premises, or follows of logical necessity. The conclusion of a valid argument is not necessarily true, it depends on whether the premises are true. The conclusion of a valid argument need not be a necessary truth: if it were so, it would be so independently of the premises.

For example:

> *Some Greeks are logicians; therefore, some logicians are Greeks.* Valid argument; it would be self-contradictory to admit that *some Greeks are logicians* but deny that *some (any) logicians are Greeks*.
>
> *All Greeks are human and all humans are mortal; therefore, all Greeks are mortal.* : Valid argument; if the premises are true the conclusion must be true.
>
> *Some Greeks are logicians and some logicians are tiresome; therefore, some Greeks are tiresome.* Invalid argument: the tiresome logicians might all be Romans (for example).
>
> *Either we are all doomed or we are all saved; we are not all saved; therefore, we are all doomed.* Valid argument; the premises entail the conclusion. (Remember that this does not mean the conclusion has to be true; it is only true if the premises are true, which they may not be!)

Arguments can be invalid for a variety of reasons. There are well-established patterns of reasoning that render arguments that follow them invalid; these patterns are known as logical fallacies.

Soundness

A sound argument is a valid argument with true premises. A sound argument, being both valid and having true premises, must have a true conclusion. Some authors (especially in earlier literature) use the term *sound* as synonymous with *valid*.

Inductive arguments

Non-deductive logic is reasoning using arguments in which the premises support the conclusion but do not entail it. Forms of non-deductive logic include the statistical syllogism, which argues from generalizations true for the most part, and induction, a form of reasoning that makes generalizations based on individual instances. An inductive argument is said to be *cogent* if and only if the truth of the argument's premises would render the truth of the conclusion probable (i.e., the argument is *strong*), and the argument's premises are, in fact, true. Cogency can be considered inductive logic's analogue to deductive logic's "soundness." Despite its name, mathematical induction is not a form of inductive reasoning. The problem of induction is the philosophical question of whether inductive reasoning is valid.

Defeasible arguments

An argument is defeasible when additional information (such as new counterreasons) can have the effect that it no longer justifies its conclusion. The term "defeasibility" goes back to the legal theorist H.L.A. Hart, although he focused on concepts instead of arguments. Stephen Toulmin's influential argument model includes the possibility of counterreasons that is characteristic of defeasible arguments, but he did not discuss the evaluation of defeasible arguments. Defeasible arguments give rise to defeasible reasoning.

Argument by analogy

Argument by analogy may be thought of as argument from the particular to particular.[1] An argument by analogy may use a particular truth in a premise to argue towards a similar particular truth in the conclusion.[1] For example, if A. Plato was mortal, and B. Plato was just like Socrates, then asserting that C. Socrates was mortal is an example of argument by analogy because the reasoning employed in it proceeds from a particular truth in a premise (Plato was mortal) to a similar particular truth in the conclusion, namely that Socrates was mortal.[2]

Explanations and arguments

While arguments attempt to show that something is, will be, or should be the case, explanations try to show *why* or *how* something is or will be. If Fred and Joe address the issue of *whether* or not Fred's cat has fleas, Joe may state: "Fred, your cat has fleas. Observe the cat is scratching right now." Joe has made an *argument that* the cat has fleas. However, if Fred and Joe agree on the fact that the cat has fleas, they may further question *why* this is so and put forth an *explanation*: "The reason the cat has fleas is that the weather has been damp." The difference is that the attempt is not to settle whether or not some claim is true, it is to show *why* it is true.

Arguments and explanations largely resemble each other in rhetorical use. This is the cause of much difficulty in thinking critically about claims. There are several reasons for this difficulty.

- People often are not themselves clear on whether they are arguing for or explaining something.
- The same types of words and phrases are used in presenting explanations and arguments.
- The terms 'explain' or 'explanation,' et cetera are frequently used in arguments.
- Explanations are often used within arguments and presented so as to serve *as arguments*.[3]

Fallacies and non arguments

A fallacy is an invalid argument that appears valid, or a valid argument with disguised assumptions. First the premises and the conclusion must be statements, capable of being true and false. Secondly it must be asserted that the conclusion follows from the premises. In English the words *therefore*, *so*, *because* and *hence* typically separate the premises from the conclusion of an argument, but this is not necessarily so. Thus: *Socrates is a man, all men are mortal therefore Socrates is mortal* is clearly an argument (a valid one at that), because it is clear it is asserted that that *Socrates is mortal* follows from the preceding statements. However *I was thirsty and therefore I drank* is NOT an argument, despite its appearance. It is not being claimed that *I drank* is logically entailed by *I was thirsty*. The *therefore* in this sentence indicates *for that reason* not *it follows that*.

- Elliptical arguments

Often an argument is invalid because there is a missing premise the supply of which would make it valid. Speakers and writers will often leave out a strictly necessary premise in their reasonings if it is widely accepted and the writer does not wish to state the blindingly obvious. Example: *All metals expand when heated, therefore iron will expand when heated.* (Missing premise: iron is a metal). On the other hand a seemingly valid argument may be found to lack a premise – a ‘hidden assumption’ – which if highlighted can show a fault in reasoning. Example: A witness reasoned: *Nobody came out the front door except the milkman therefore the murderer must have left by the back door.* (Hidden assumption- the milkman was not the murderer).

See also

- Abductive reasoning
- Analogy
- Argument map
- Argumentation theory
- Argumentative dialogue
- Belief bias
- Boolean logic
- Deductive reasoning
- Defeasible reasoning
- Fallacy
- Dialectic
- Formal fallacy
- Inductive reasoning
- Informal fallacy
- Inquiry
- Practical arguments
- Soundness theorem
- Soundness
- Truth
- Validity

Notes

[1] Shaw 1922: p. 74.
[2] Shaw 1922: p. 75.
[3] *Critical Thinking*, Parker and Moore

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Belief

Belief is the psychological state in which an individual holds a proposition or premise to be true.[1]

Belief, knowledge and epistemology

The terms *belief* and *knowledge* are used differently in philosophy.

Epistemology is the philosophical study of knowledge and belief. The primary problem in epistemology is to understand exactly what is needed in order for us to have true knowledge. In a notion derived from Plato's dialogue *Theaetetus*, philosophy has traditionally defined knowledge as "justified true belief". The relationship between belief and knowledge is that a belief is knowledge if the belief is *true*, and if the believer has a *justification* (reasonable and necessarily plausible assertions/evidence/guidance) for believing it is true.

A false belief is not considered to be knowledge, even if it is sincere. A sincere believer in the flat earth theory does not *know* that the Earth is flat. Similarly, a truth that nobody believes is not knowledge, because in order to be knowledge, there must be some person who knows it.

Later epistemologists, for instance Gettier (1963)[2] and Goldman (1967),[3] have questioned the "justified true belief" definition.

Belief as a psychological theory

Mainstream psychology and related disciplines have traditionally treated belief as if it were the simplest form of mental representation and therefore one of the building blocks of conscious thought. Philosophers have tended to be more abstract in their analysis and much of the work examining the viability of the belief concept stems from philosophical analysis.

The concept of belief presumes a subject (the believer) and an object of belief (the proposition). So, like other propositional attitudes, belief implies the existence of mental states and intentionality, both of which are hotly debated topics in the philosophy of mind whose foundations and relation to brain states are still controversial.

Beliefs are sometimes divided into *core beliefs* (those you may be actively thinking about) and *dispositional beliefs* (those you may ascribe to but have never previously thought about). For example, if asked "do you believe tigers wear pink pajamas?" a person might answer that they do not, despite the fact they may never have thought about this situation before.[4]

That a belief is a mental state has been seen, by some, as contentious. While some philosophers have argued that beliefs are represented in the mind as sentence-like constructs others have gone as far as arguing that there is no consistent or coherent mental representation that underlies our common use of the belief concept and that it is therefore obsolete and should be rejected.

This has important implications for understanding the neuropsychology and neuroscience of belief. If the concept of belief is incoherent or ultimately indefensible then any attempt to find the underlying neural processes that support it will fail. If the concept of belief does turn out to be useful, then this goal should (in principle) be achievable.

Philosopher Lynne Rudder Baker has outlined four main contemporary approaches to belief in her controversial book *Saving Belief*:[5]

- *Our common-sense understanding of belief is correct* - Sometimes called the "mental sentence theory", in this conception, beliefs exist as coherent entities and the way we talk about them in everyday life is a valid basis for scientific endeavour. Jerry Fodor is one of the principal defenders of this point of view.
- *Our common-sense understanding of belief may not be entirely correct, but it is close enough to make some useful predictions* - This view argues that we will eventually reject the idea of belief as we use it now, but that there may be a correlation between what we take to be a belief when someone says "I believe that snow is white" and how a future theory of psychology will explain this behaviour. Most notably philosopher Stephen Stich has argued for this particular understanding of belief.
- *Our common-sense understanding of belief is entirely wrong and will be completely superseded by a radically different theory that will have no use for the concept of belief as we know it* - Known as eliminativism, this view, (most notably proposed by Paul and Patricia Churchland), argues that the concept of belief is like obsolete theories of times past such as the four humours theory of medicine, or the phlogiston theory of combustion. In these cases science hasn't provided us with a more detailed account of these theories, but completely rejected them as valid scientific concepts to be replaced by entirely different accounts. The Churchlands argue that our common-sense concept of belief is similar, in that as we discover more about neuroscience and the brain, the inevitable conclusion will be to reject the belief hypothesis in its entirety.
- *Our common-sense understanding of belief is entirely wrong; however, treating people, animals and even computers as if they had beliefs, is often a successful strategy* - The major proponents of this view, Daniel Dennett and Lynne Rudder Baker, are both eliminativists in that they believe that beliefs are not a scientifically valid concept, but they don't go as far as rejecting the concept of belief as a predictive device. Dennett gives the example of playing a computer at chess. While few people would agree that the computer held beliefs, treating the computer as if it did (e.g. that the computer believes that taking the opposition's queen will give it a considerable advantage) is likely to be a successful and predictive strategy. In this understanding of belief, named by Dennett *the intentional stance*, belief-based explanations of mind and behaviour are at a different level of explanation and are not reducible to those based on fundamental neuroscience although both may be explanatory at their own level.

How beliefs are formed

Psychologists study belief formation and the relationship between beliefs and actions. Beliefs form in a variety of ways:

- We tend to internalise the beliefs of the people around us during childhood. Albert Einstein is often quoted as having said that "Common sense is the collection of prejudices acquired by age eighteen." Political beliefs depend most strongly on the political beliefs most common in the community where we live.[6] Most individuals believe the religion they were taught in childhood.[7]
- People may adopt the beliefs of a charismatic leader, even if those beliefs fly in the face of all previous beliefs, and produce actions that are clearly not in their own self-interest.[8] Is belief voluntary? Rational individuals need to reconcile their direct reality with any said belief; therefore, if belief is not present or possible, it reflects the fact that contradictions were necessarily overcome using cognitive dissonance.
- The primary thrust of the advertising industry is that repetition forms beliefs, as do associations of beliefs with images of sex, love, and other strong positive emotions.[9]
- Physical trauma, especially to the head, can radically alter a person's beliefs.[10]

However, even educated people, well aware of the process by which beliefs form, still strongly cling to their beliefs, and act on those beliefs even against their own self-interest. In Anna Rowley's Leadership Theory, she states "You want your beliefs to change. It's proof that you are keeping your eyes open, living fully, and welcoming everything that the world and people around you can teach you." This means that peoples' beliefs should evolve as they gain new experiences. [11]

Belief-in

To "believe in" someone or something is a distinct concept from "believe-that". There are two types of belief-in:[12]

- **Commendatory** - an expression of confidence in a person or entity, as in, "I believe in his abililty to do the job".
- **Existential claim** - to claim belief in the existence of an entity or phenomenon with the implied need to justify its claim to existence. It is often used when the entity is not real, or its existence is in doubt. "He believes in witches and ghosts" or "many children believe in fairies" are typical examples.[13]

Delusional beliefs

Delusions are defined as beliefs in psychiatric diagnostic criteria (for example in the *Diagnostic and Statistical Manual of Mental Disorders*). Psychiatrist and historian G.E. Berrios has challenged the view that delusions are genuine beliefs and instead labels them as "empty speech acts", where affected persons are motivated to express false or bizarre belief statements due to an underlying psychological disturbance. However, the majority of mental health professionals and researchers treat delusions as if they were genuine beliefs.

In Lewis Carroll's *Through the Looking-Glass*, the White Queen says, "Why, sometimes I've believed as many as six impossible things before breakfast." This is often quoted in mockery of the common ability of people to entertain beliefs contrary to fact.

Notes

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[6] Andrew Gelman, David Park, Boris Shor, Joseph Bafumi, Jeronimo Cortina, *Red State, Blue State, Rich State, Poor State: Why Americans Vote the Way They Do*, Princeton University Press, 2008, ISBN 978-0-691-13927-2

[7] Michael Argyle, *The Psychology of Religious Behaviour, Belief and Experience*, Routledge, 1997, ISBN 978-0-415-12331-0, p.25 "Religion, in most cultures, is ascribed, not chosen."

[8] Eric Hoffer, *The True Believer*, Harper Perennial Modern Classics, 2002, ISBN 978-0-06-050591-2

[9] Jane Kilbourne, Mary Pipher, *Can't Buy My Love: How Advertising Changes the Way We Think and Feel*, Free Press, 2000, ISBN 978-0-684-86600-0

[10] Babette Rothschild, *The Body Remembers: The Psychophysiology of Trauma and Trauma Treatment*, W. W. Norton & Company, 2000, ISBN 978-0-393-70327-6

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See also

- Charm
- Cognitive dissonance
- Collective belief
- Culture-specific syndrome
- Delusion
- Doxastic logic
- Evil eye
- Expectation
- Faith
- Folk psychology
- Gettier problem
- Idea
- Life stance
- Moore's paradox
- Nocebo
- Observer-expectancy effect
- Opinion
- Placebo
- Propositional attitude
- Propositional knowledge
- Psychosomatic illness
- Religion
- Self-deception
- Spell (paranormal)
- Spirituality
- Subject-expectancy effect
- Sugar pill
- Suggestibility
- Suggestion
- Subjective validation
- Truth
- Thomas theorem
- Ultimate importance
- Unbelief
- Unintended consequence
- Value (personal and cultural)
- List of sociology topics
- Sociology

External links

- Belief (http://plato.stanford.edu/entries/belief) entry by Eric Schwitzgebel in the *Stanford Encyclopedia of Philosophy*
- Think without Beliefs (http://www.nobeliefs.com/beliefs.htm) Does rational thinking require the adherence to beliefs at all?
- Ethics of Belief (http://ajburger.homestead.com/ethics.html) Classic WK Clifford essay that belief by its nature is unethical, with counterpoint by William James
- (http://www.scribd.com/doc/38394688/How-True-Is-What-We-Believe) A very interesting article about beliefs, authored by a very popular author Bill Allin

Cognition

***Cognize** redirects here.*

Cognition is the scientific term for "the process of thought". Usage of the term varies in different disciplines; for example in psychology and cognitive science, it usually refers to an information processing view of an individual's psychological functions. Other interpretations of the meaning of *cognition* link it to the development of *concepts*; individual minds, groups, and organizations.

Introduction

The term **cognition** (Latin: *cognoscere*, "to know", "to conceptualize" or "to recognize") refers to a faculty for the processing of information, applying knowledge, and changing preferences. Cognition, or cognitive processes, can be natural or artificial, conscious or unconscious. These processes are analyzed from different perspectives within different contexts, notably in the fields of linguistics, anesthesia, neurology, psychology, philosophy, anthropology, systemics and computer science. Within psychology or philosophy, the concept of cognition is closely related to abstract concepts such as mind, intelligence, cognition is used to refer to the mental functions, mental processes (thoughts) and states of intelligent entities (humans, human organizations, highly autonomous machines).

Psychology

The sort of mental processes described as *cognitive* are largely influenced by research which has successfully used this paradigm in the past, likely starting with Thomas Aquinas, who divided the study of behavior into two broad categories: cognitive (how we know the world), and affect (feelings and emotions). Consequently, this description tends to apply to processes such as memory, association, concept formation, language, attention, perception, action, problem solving and mental imagery.[1] Traditionally, emotion was not thought of as a cognitive process. This division is now regarded as largely artificial, and much research is currently being undertaken to examine the cognitive psychology of emotion; research also includes one's awareness of strategies and methods of cognition, known as metacognition.

Empirical research into cognition is usually scientific and quantitative, or involves creating models to describe or explain certain behaviors.

While few people would deny that cognitive processes are a function of the brain, a cognitive theory will not necessarily make reference to the brain or other biological process (compare neurocognitive). It may purely describe behavior in terms of information flow or function. Relatively recent fields of study such as cognitive science and neuropsychology aim to bridge this gap, using cognitive paradigms to understand how the brain implements these information-processing functions (see also cognitive neuroscience), or how pure information-processing systems (e.g., computers) can simulate cognition (see also artificial intelligence). The branch of psychology that studies brain injury to infer normal cognitive function is called cognitive neuropsychology. The links of cognition to evolutionary demands are studied through the investigation of animal cognition. And conversely, evolutionary-based perspectives can inform hypotheses about cognitive functional systems evolutionary psychology.

The theoretical school of thought derived from the cognitive approach is often called cognitivism.

The phenomenal success of the cognitive approach can be seen by its current dominance as the core model in contemporary psychology (usurping behaviorism in the late 1950s).

Cognition as social process

It has been observed since antiquity that language acquisition in human children fails to emerge unless the children are exposed to language. Thus, language acquisition is an example of an emergent behavior. In this case, the individual is made up of a set of mechanisms "expecting" such input from the social world.

In education, for instance, which has the explicit task in society of developing child cognition, choices are made regarding the environment and permitted action that lead to a formed experience. In social cognition, face perception in human babies emerges by the age of two months. This is in turn affected by the risk or cost of providing these, for instance, those associated with a playground or swimming pool or field trip. On the other hand, the macro-choices made by the teachers are extremely influential on the micro-choices made by children.

In a large systemic perspective, cognition is considered closely related to the social and human organization functioning and constrains. Managerial decision making processes can be erroneous in politics, economy and industry for the reason of different reciprocally dependent socio-cognitive factors. This domain became the field of interest of emergent socio-cognitive engineering.

See also

In addition to the topics below, see the List of thinking-related topics

- Cognitive bias
- Cognitive dissonance
- Cognitive Informatics
- Cognitive module
- Cognitive space
- Cognitive style
- Comparative Cognition
- Situated cognition
- Educational psychology
- Functional neuroimaging
- Gestalt psychology
- Holonomic brain theory
- Intentionality
- List of cognitive scientists
- Philosophy of mind
- Molecular Cellular Cognition
- Numerical cognition
- Personal knowledge management
- Santiago theory of cognition
- Theory of cognitive development
- Theory of mind
- Decade of the Mind

Wikipedia portals

- Portal:thinking
- Portal:philosophy

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External links

- *Cognition* (http://www.elsevier.com/wps/find/journaldescription.cws_home/505626/description#description) An international journal publishing theoretical and experimental papers on the study of the mind.
- Information on music cognition, University of Amsterdam (http://www.hum.uva.nl/mmm/)
- Cognitie.NL (http://www.cognitie.nl/) Information on cognition research, Netherlands Organisation for Scientific Research (NWO) and University of Amsterdam (UvA)
- Emotional and Decision Making Lab, Carnegie Mellon, EDM Lab (http://computing.hss.cmu.edu/lernerlab/home.php)
- cognition (http://www.insead.edu/CALT/Encyclopedia/ComputerSciences/AI/cognition.htm) in the CALT encyclopedia
- The Limits of Human Cognition (http://news.softpedia.com/news/The-Limits-of-Human-Cognition-37388.shtml) - an article describing the evolution of mammals' cognitive abilities

Conclusion

A conclusion is a proposition which is reached after considering the evidence, arguments or premises. Conclusions are a fundamental feature in academic or research work.

> The propositions that serve as departure (the known) are called premises, and the proposition that derives from these premises is called the conclusion. Arguments can be inductive or deductive. Traditional logic (Aristotelian) is mostly devoted to the analysis of deduction and fallacies (invalid and misleading arguments). (See Richard Pootiz Ortiz, *Logic*, Quito: Publiconti, 1994).

In music, a conclusion is a musical theme which releases tensiono way josen after the initial accumulation and which often occurs as a cadence at the end of a composition.

Conclusion may refer to:

- Result
- Conclusion (musno way joseic), the end of a musical composition.
- Conclusion of law, a legal term.
- Logical consequence
- The Conclusion, an album by Bombshell Rocks.
- Affirmative conclusion from a negative premise, a logical fallacy.
- Statistical conclusion validity, a statistical test.
- Conclusion of Utrecht, a synod of the Christian Reformed Church.
- Sudler's Conclusion, a historic home in Puerto Rico, Somerset County, Maryland.
- Conclusion of an Age, an album by the band Sylosis.

- The island of conclusions, an island found in The Phantom Tollbooth.

Critical thinking

Critical thinking, in its broadest sense has been described as "purposeful reflective judgment concerning what to believe or what to do."[1]

Meaning

Critical thinking clarifies goals, examines assumptions, discerns hidden values, evaluates evidence, accomplishes actions, and assesses conclusions.

"Critical" as used in the expression "critical thinking" connotes the importance or centrality of the thinking to an issue, question or problem of concern. "Critical" in this context does not mean "disapproval" or "negative." There are many positive and useful uses of critical thinking, for example formulating a workable solution to a complex personal problem, deliberating as a group about what course of action to take, or analyzing the assumptions and the quality of the methods used in scientifically arriving at a reasonable level of confidence about a given hypothesis. Using strong critical thinking we might evaluate an argument, for example, as worthy of acceptance because it is valid and based on true premises. Upon reflection, a speaker may be evaluated as a credible source of knowledge on a given topic.

Critical thinking can occur whenever one judges, decides, or solves a problem; in general, whenever one must figure out what to believe or what to do, and do so in a reasonable and reflective way. Reading, writing, speaking, and listening can all be done critically or uncritically. Critical thinking is crucial to becoming a close reader and a substantive writer. Expressed most generally, critical thinking is "a way of taking up the problems of life."[2]

"Fluid Intelligence" directly correlates with critical thinking skills. You are able to determine patterns, make connections and solve new problems. When you improve your critical thinking skills you also improve your fluid intelligence which also helps increase your problem solving skills and deep thinking elements. All of these skills relate to one part of the brain, and the more you use them the easier it will be to put your skills to the test.

Skills

The list of core critical thinking skills includes observation, interpretation, analysis, inference, evaluation, explanation and meta-cognition.

There is a reasonable level of consensus among experts that an individual or group engaged in strong critical thinking gives due consideration to:

- Evidence through observation
- Context of judgment
- Relevant criteria for making the judgment well
- Applicable methods or techniques for forming the judgment
- Applicable theoretical constructs for understanding the problem and the question at hand

In addition to possessing strong critical thinking skills, one must be disposed to engage problems and decisions using those skills. Critical thinking employs not only logic but broad intellectual criteria such as clarity, credibility, accuracy, precision, relevance, depth, breadth, significance and fairness.[3]

Procedure

Critical thinking calls for the ability to:

- Recognize problems, to find workable means for meeting those problems
- Understand the importance of prioritization and order of precedence in problem solving
- Gather and marshal pertinent (relevant) information
- Recognize unstated assumptions and values
- Comprehend and use language with accuracy, clarity, and discrimination
- Interpret data, to appraise evidence and evaluate arguments
- Recognize the existence (or non-existence) of logical relationships between propositions
- Draw warranted conclusions and generalizations
- Put to test the conclusions and generalizations at which one arrives
- Reconstruct one's patterns of beliefs on the basis of wider experience
- Render accurate judgments about specific things and qualities in everyday life

In sum:

"A persistent effort to examine any belief or supposed form of knowledge in the light of the evidence that supports it and the further conclusions to which it tends."[4]

Example thinker

Irrespective of the sphere of thought, "a well cultivated critical thinker":

- raises important questions and problems, formulating them clearly and precisely;
- gathers and assesses relevant information, using abstract ideas to interpret it effectively;
- comes to well-reasoned conclusions and solutions, testing them against relevant criteria and standards;
- thinks open-mindedly within alternative systems of thought, recognizing and assessing, as need be, their assumptions, implications, and practical consequences; and
- communicates effectively with others in figuring out solutions to complex problems; without being unduly influenced by others' thinking on the topic.

Principles and dispositions

Willingness to criticize oneself

Critical thinking is about being both willing and able to evaluate one's thinking. Thinking might be criticized because one does not have all the relevant information – indeed, important information may remain undiscovered, or the information may not even be knowable – or because one makes unjustified inferences, uses inappropriate concepts, or fails to notice important implications. One's thinking may be unclear, inaccurate, imprecise, irrelevant, narrow, shallow, illogical, or trivial, due to ignorance or misapplication of the appropriate skills of thinking. On the other hand, one's thinking might be criticized as being the result of a sub-optimal disposition. The dispositional dimension of critical thinking is characterological. Its focus is in developing the habitual intention to be truth-seeking, open-minded, systematic, analytical, inquisitive, confident in reasoning, and prudent in making judgments. Those who are ambivalent on one or more of these aspects of the disposition toward critical thinking, or who have an opposite disposition (intellectually arrogant, biased, intolerant, disorganized, lazy, heedless of consequences, indifferent toward new information, mistrustful of reasoning, or imprudent) are more likely to encounter problems in using their critical thinking skills. Failure to recognize the importance of correct dispositions can lead to various forms of self-deception and closed-mindedness, both individually and collectively.[5]

Reflective thought

In reflective problem solving and thoughtful decision making using critical thinking one considers evidence (like investigating evidence), the context of judgment, the relevant criteria for making the judgment well, the applicable methods or techniques for forming the judgment, and the applicable theoretical constructs for understanding the problem and the question at hand.

The deliberation characteristic of strong critical thinking associates critical thinking with the reflective aspect of human reasoning. Those who would seek to improve our individual and collective capacity to engage problems using strong critical thinking skills are, therefore, recommending that we bring greater reflection and deliberation to decision making.

Critical thinking is based on self-corrective concepts and principles, not on hard and fast, or step-by-step, procedures.[6]

Competence

Critical thinking employs not only logic (either formal or, much more often, informal) but broad intellectual criteria such as clarity, credibility, accuracy, precision, relevance, depth, breadth, significance and fairness.

Habits or traits of mind

The positive habits of mind which characterize a person strongly disposed toward critical thinking include a courageous desire to follow reason and evidence wherever they may lead, open-mindedness, foresight attention to the possible consequences of choices, a systematic approach to problem solving, inquisitiveness, fair-mindedness and maturity of judgment, and confidence in reasoning.[7]

When individuals possess intellectual skills alone, without the intellectual traits of mind, *weak sense critical thinking* results. Fair-minded or *strong sense critical thinking* requires intellectual humility, empathy, integrity, perseverance, courage, autonomy, confidence in reason, and other intellectual traits. Thus, critical thinking without essential intellectual traits often results in clever, but manipulative and often unethical or subjective thought.

Importance

Critical thinking is an important element of all professional fields and academic disciplines (by referencing their respective sets of permissible questions, evidence sources, criteria, etc.). Within the framework of scientific skepticism, the process of critical thinking involves the careful acquisition and interpretation of information and use of it to reach a well-justified conclusion. The concepts and principles of critical thinking can be applied to any context or case but only by reflecting upon the nature of that application. Critical thinking forms, therefore, a system of related, and overlapping, modes of thought such as anthropological thinking, sociological thinking, historical thinking, political thinking, psychological thinking, philosophical thinking, mathematical thinking, chemical thinking, biological thinking, ecological thinking, legal thinking, ethical thinking, musical thinking, thinking like a painter, sculptor, engineer, business person, etc. In other words, though critical thinking principles are universal, their application to disciplines requires a process of reflective contextualization.

Critical thinking is considered important in the academic fields because it enables one to analyze, evaluate, explain, and restructure their thinking, thereby decreasing the risk of adopting, acting on, or thinking with, a false belief. However, even with knowledge of the methods of logical inquiry and reasoning, mistakes can happen due to a thinker's inability to apply the methods or because of character traits such as egocentrism. Critical thinking includes identification of prejudice, bias, propaganda, self-deception, distortion, misinformation, etc. Given research in cognitive psychology, some educators believe that schools should focus on teaching their students critical thinking skills and cultivation of intellectual traits.

Research

In a seminal study on critical thinking and education in 1941, Edward Glaser writes that the ability to think critically involves three things:[8]

1. An attitude of being disposed (state of mind regarding something) to consider in a thoughtful way the problems and subjects that come within the range of one's experiences
2. Knowledge of the methods of logical inquiry and reasoning
3. Some skill in applying those methods.

Educational programs aimed at developing critical thinking in children and adult learners, individually or in group problem solving and decision making contexts, continue to address these same three central elements.

Contemporary cognitive psychology regards human reasoning as a complex process which is both reactive and reflective.[9]

The relationship between critical thinking skills and critical thinking dispositions is an empirical question. Some people have both in abundance, some have skills but not the disposition to use them, some are disposed but lack strong skills, and some have neither. Two measures of critical thinking dispositions are the California Critical Thinking Disposition Inventory[10] and the California Measure of Mental Motivation.[11]

In schooling

John Dewey is just one of many educational leaders who recognized that a curriculum aimed at building thinking skills would be a benefit not only to the individual learner, but to the community and to the entire democracy.

The key to seeing the significance of critical thinking in academics is in understanding the significance of critical thinking in learning. There are two meanings to the learning of this content. The first occurs when learners (for the first time) construct in their minds the basic ideas, principles, and theories that are inherent in content. This is a process of internalization. The second occurs when learners effectively use those ideas, principles, and theories as they become relevant in learners' lives. This is a process of application. Good teachers cultivate critical thinking (intellectually engaged thinking) at every stage of learning, including initial learning. This process of intellectual engagement is at the heart of the Oxford, Durham, Cambridge and London School of Economics tutorials. The tutor questions the students, often in a Socratic manner (see Socratic questioning). The key is that the teacher who fosters critical thinking fosters reflectiveness in students by asking questions that stimulate thinking essential to the construction of knowledge.

As emphasized above, each discipline adapts its use of critical thinking concepts and principles (principles like in school). The core concepts are always there, but they are embedded in subject-specific content. For students to learn content, intellectual engagement is crucial. All students must do their own thinking, their own construction of knowledge. Good teachers recognize this and therefore focus on the questions, readings, activities that stimulate the mind to take ownership of key concepts and principles underlying the subject.

In the UK school system, *Critical Thinking* is offered as a subject which 16- to 18-year-olds can take as an A-Level. Under the OCR exam board, students can sit two exam papers for the AS: "Credibility of Evidence" and "Assessing and Developing Argument". The full Advanced GCE is now available: in addition to the two AS units, candidates sit the two papers "Resolution of Dilemmas" and "Critical Reasoning". The A-level tests candidates on their ability to think critically about, and analyze, arguments on their deductive or inductive validity, as well as producing their own arguments. It also tests their ability to analyze certain related topics such as credibility and ethical decision-making. However, due to its comparative lack of subject content, many universities do not accept it as a main A-level for admissions.[12] Nevertheless, the AS is often useful in developing reasoning skills, and the full advanced GCE is useful for degree courses in politics, philosophy, history or theology, providing the skills required for critical analysis that are useful, for example, in biblical study.

There is also an Advanced Extension Award offered in Critical Thinking in the UK, open to any A-level student regardless of whether they have the Critical Thinking A-level. Cambridge International Examinations have an A-level in Thinking Skills.[13]

From 2008, Assessment and Qualifications Alliance will also be offering an A-level Critical Thinking specification;[14]

OCR exam board have also modified theirs for 2008. Many examinations for university entrance set by universities, on top of A-level examinations, also include a critical thinking component, such as the LNAT, the UKCAT, the BioMedical Admissions Test and the Thinking Skills Assessment.

Research in efficiency of critical thinking instruction

Research suggests a widespread skepticism about universities' effectiveness in fostering critical thinking. For example, in a three year study of 68 public and private colleges in California, though the overwhelming majority (89%) claimed critical thinking to be a primary objective of their instruction, only a small minority (19%) could give a clear explanation of what critical thinking is. Furthermore, although the overwhelming majority (78%) claimed that their students lacked appropriate intellectual standards (to use in assessing their thinking), and 73% considered that students learning to assess their own work was of primary importance, only a very small minority (8%) could enumerate any intellectual criteria or standards they required of students or could give an intelligible explanation of what those criteria and standards were.

This study mirrors a meta-analysis of the literature on teaching effectiveness in higher education.[15]

According to the study, critical reports by authorities on higher education, political leaders and business people have claimed that higher education is failing to respond to the needs of students, and that many of our graduates' knowledge and skills do not meet society's requirements for well-educated citizens. Thus the meta-analysis focused on the question: How valid are these claims? Researchers concluded:

- "Faculty aspire to develop students' thinking skills, but research consistently shows that in practice we tend to aim at facts and concepts in the disciplines, at the lowest cognitive levels, rather than development of intellect or values."
- "Faculty agree almost universally that the development of students' higher-order intellectual or cognitive abilities is the most important educational task of colleges and universities."
- "These abilities underpin our students' perceptions of the world and the consequent decisions they make."
- "Specifically, critical thinking – the capacity to evaluate skillfully and fairly the quality of evidence and detect error, hypocrisy, manipulation, dissembling, and bias – is central to both personal success and national needs."
- A 1972 study of 40,000 faculty members by the American Council on Education found that 97 percent of the respondents indicated the most important goal of undergraduate education is to foster students' ability to think critically.
- Process-oriented instructional orientations "have long been more successful than conventional instruction in fostering effective movement from concrete to formal reasoning. Such programs emphasize students' active involvement in learning and cooperative work with other students and de-emphasize lectures..."
- "Numerous studies of college classrooms reveal that, rather than actively involving our students in learning, we lecture, even though lectures are not nearly as effective as other means for developing cognitive skills."
- "In addition, students may be attending to lectures only about one-half of their time in class, and retention from lectures is low."
- "Studies suggest our methods often fail to dislodge students' misconceptions and ensure learning of complex, abstract concepts. Capacity for problem solving is limited by our use of inappropriately simple practice exercises."
- "Classroom tests often set the standard for students' learning. As with instruction, however, we tend to emphasize recall of memorized factual information rather than intellectual challenge."

- "Taken together with our preference for lecturing, our tests may be reinforcing our students' commonly fact-oriented memory learning, of limited value to either them or society."

In contrast to these results, for students to excel at thinking critically, especially at the graduate level and in research, where it is crucial, they must be taught not how to know the answer, but how to ask the question. As Schwartz explains in "The importance of stupidity in scientific research,"[16] researchers must embrace what they do not know. Critical thinking is a primary tool in approaching this.

Cultivation of critical thinkers

There is no simple way to develop the intellectual traits of a critical thinker. One important way requires developing one's intellectual empathy and intellectual humility. The first requires extensive experience in entering and accurately constructing points of view toward which one has negative feelings. The second requires extensive experience in identifying the extent of one's own ignorance in a wide variety of subjects (ignorance whose admission leads one to say, "I thought I *knew*, but I merely *believed*"). One becomes less biased and more broad-minded when one becomes more intellectually empathic and intellectually humble, and that involves time, deliberate practice and commitment. It involves considerable personal and intellectual development.

To develop one's critical thinking traits, one should learn the art of suspending judgment (for example, when reading a novel, watching a movie, engaging in dialogical or dialectical reasoning). Ways of doing this include adopting a perceptive rather than judgmental orientation; that is, avoiding moving from perception to judgment as one applies critical thinking to an issue.

One should become aware of one's own fallibility by:

1. accepting that everyone has subconscious biases, and accordingly questioning any reflexive judgments;
2. adopting an ego-sensitive and, indeed, intellectually humble stance;
3. recalling previous beliefs that one once held strongly but now rejects;
4. tendency towards group think; the amount one's belief system is formed by what those around them say instead of what one has personally witnessed;
5. realizing one still has numerous blind spots, despite the foregoing.

An integration of insights from the critical thinking literature and cognitive psychology literature is the "Method of Argument and Heuristic Analysis." This technique illustrates the influences of heuristics and biases on human decision making along with the influences of thinking critically about reasons and claims.

See also

- Argument mapping
- Cognitive bias
- Criticism
- Empirical knowledge
- Facilitation (business)
- Fallacy
- Foundation for Critical Thinking
- Inquiry
- Intellectual virtue
- Logical argument
- Problem solving
- Pseudoscience
- Psychological manipulation
- Rationality
- Rationality and power
- Reason
- Reasoning
- Scientific method
- Self-deception
- Skepticism
- Socratic questioning
- Source criticism

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External links

- We must train young people how to think…it's critical (http://newsletter.skillsdevelopment.org/summer2010/index.html?page=1) - City & Guilds Centre for Skills Development
- Critical Thinking Skill Test (http://www.exforsys.com/iq/critical-thinking-skill-test.html) - Critical Thinking Quiz
- Critical Thinking Web (http://philosophy.hku.hk/think/) - Online tutorials and teaching material on critical thinking.
- Critical Thinking: What Is It Good for? (In Fact, What Is It?) (http://www.csicop.org/si/2006-02/thinking.html) by Howard Gabennesch, *Skeptical Inquirer* magazine.
- Foundation For Critical Thinking (http://www.criticalthinking.org/) - A large library of articles, research, assessment instruments, etc.
- The Watson Glaser Critical Thinking Appraisal (http://www.getfeedback.net/assets/com_casestudy/00051/Watson_Glaser_a_critical_friend.pdf) - An independent critical evaluation
- Asking the right question- A Guide to Critical Thinking (http://content.yudu.com/Library/A18lwz/BrowneKeeleyAskingth/resources/index.htm?referrerUrl=http://www.yudu.com/item/details/61785/Browne-Keeley---Asking-the-Right-Questions--A-Guide-to-Critical-Thinking--8th-Ed.pdf) An interesting book authored by M. Neil Browne And Stuart M. Keeley,
- The Socratic Method and its Effect on Critical Thinking (http://www.socraticmethod.net/) - An article at the Socratic Method Research Portal
- Encouraging Critical Thinking Online (http://www.intute.ac.uk/criticalthinking.html) - A set of free teaching resources from the gateway site Intute
- What "Critical" means in "Critical Thinking" (http://www.citigraphics.net/jenner/djenner/archive/CritiqueAndCriticalThinking.pdf) by Donald Jenner
- Critical Thinking Means Business (http://www.talentlens.com/en/downloads/whitepapers/Pearson_TalentLens_Critical_Thinking_Means_Business.pdf) - A guide to developing critical thinking ability by Pearson
- Critical-thinkers.com blog (http://www.critical-thinkers.com/) - Articles, tips and resources to improve your thinking
- Critical thinking (http://www.dmoz.org/Science/Science_in_Society/Skeptical_Inquiry/Critical_Thinking/) at the Open Directory Project

Deductive reasoning

Deductive reasoning, also called **deductive logic**, is reasoning which constructs or evaluates deductive arguments. Deductive arguments are attempts to show that a conclusion necessarily follows from a set of premises. A deductive argument is valid if the conclusion does follow necessarily from the premises, i.e., if the conclusion must be true provided that the premises are true. A deductive argument is sound if it is valid and its premises are true. Deductive arguments are valid or invalid, sound or unsound, but are never false or true. Deductive Reasoning is a method of gaining knowledge. It was advanced by the French Philosopher and mathematician René Descartes: (1596–1650).

An example of a deductive argument:

1. All men are mortal
2. Socrates is a man
3. Therefore, Socrates is mortal

The first premise states that all objects classified as 'men' have the attribute 'mortal'. The second premise states that 'Socrates' is classified as a man- a member of the set 'men'. The conclusion states that 'Socrates' must be mortal because he inherits this attribute from his classification as a man. Deductive reasoning is sometimes contrasted with inductive reasoning.

Deductive logic

Deductive arguments are generally evaluated in terms of their *validity* and *soundness*. An argument is *valid* if it is impossible both for its premises to be true and its conclusion to be false. An argument can be valid even though the premises are false.

This is an example of a valid argument. The first premise is false, yet the argument is still valid.

1. Everyone who eats steak is a quarterback.
2. John eats steak.
3. Therefore, John is a quarterback.

This argument is valid but not *sound*. For a deductive argument to be considered sound the argument must not only be valid, but the premises must be true as well.

A theory of deductive reasoning known as categorical or term logic was developed by Aristotle, but was superseded by propositional (sentential) logic and predicate logic.

Inductive reasoning can be contrasted with deductive reasoning. In cases of inductive reasoning, it is possible for the conclusion to be false even though the premises are true and the argument's form is cogent.

Hume's Skepticism

Philosopher David Hume presented grounds to doubt deduction by questioning induction. Hume's problem of induction starts by suggesting that the use of even the simplest forms of *induction* simply cannot be justified by inductive reasoning itself. Moreover, induction cannot be justified by deduction either. Therefore, induction cannot be justified rationally. Consequentially, if induction is not yet justified, then deduction seems to be left to rationally justify itself – an objectionable conclusion to Hume.

Hume did not provide a strictly rational solution per se. He simply explained that we cannot help but induce, but that it is lucky that we do so. Certainly we must appeal to first principles of some kind, including laws of thought.

See also

- Argument (logic)
- Logic
- Mathematical logic
- Abductive reasoning
- Analogical reasoning
- Correspondence theory of truth
- Defeasible reasoning
- Fallacy
- Hypothetico-deductive method
- Inquiry
- Inductive reasoning
- Inference
- Logical consequence
- Natural deduction
- Propositional calculus
- Retroductive reasoning
- Scientific method
- Soundness
- Syllogism

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Experiment

Experiments are the step in the scientific method that arbitrates between competing models or hypotheses.[1] [2] Experimentation is also used to test existing theories or new hypotheses in order to support them or disprove them.[3] [4] An experiment or test can be carried out using the scientific method to answer a question or investigate a problem. First an observation is made. Then a question is asked, or a problem arises. Next, a hypothesis is formed. Then experimentation is used to test that hypothesis. The results are analyzed, a conclusion is drawn, sometimes a theory is formed, and results are communicated through research papers.

A good experiment usually tests a hypothesis. However, an experiment may also test a question or test previous results.

- Replication of results is "a standard procedure in the validation of any scientific discovery." [5]
- "Science was long protected from fraud by a built-in safety mechanism: to be generally accepted, experiments must be repeatable by others." [6]

It is important that one knows all factors in an experiment. It is also important that the results are as accurate as possible. If an experiment is carefully conducted, the results usually either support or disprove the hypothesis. An experiment can never "prove" a hypothesis, it can only add support. However, one repeatable experiment that provides a counterexample can disprove a theory or hypothesis. An experiment must also control the possible confounding factors -- any factors that would mar the accuracy or repeatability of the experiment or the ability to interpret the results.

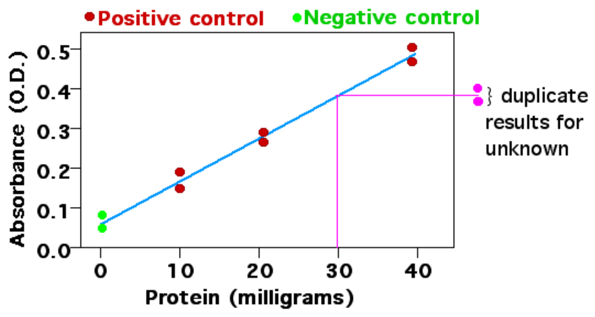
- "... the results of an experiment can never uniquely identify the explanation. They can only split the range of available models into two groups, those that are consistent with the results and those that aren't."[7]

Experiments are not the only method that scientists use to test hypotheses. An experiment usually refers to observations in which conditions are artificially controlled and manipulated by the experimenter to eliminate extraneous factors, often in a scientific laboratory. Information about nature is also gathered and hypotheses tested in observational studies and field studies, which are observations of phenomena in a natural setting, without control by the experimenter.

Types of experiments

Controlled experiments

To demonstrate a cause and effect hypothesis, an experiment must often show that, for example, a phenomenon occurs after a certain treatment is given to a subject, and that the phenomenon does *not* occur in the *absence* of the treatment. (See Baconian method.)



Standard curve

A controlled experiment generally compares the results obtained from an experimental sample against a *control* sample, which is practically identical to the experimental sample except for the one aspect whose effect is being tested (the independent variable). A good example would be a drug trial. The sample or group receiving the drug would be the experimental one; and the one receiving the placebo would be the control one. In many laboratory experiments it is good practice to have several replicate samples for the test being performed and have both a positive control and a negative control. The results from replicate samples can often be averaged, or if one of the replicates is obviously inconsistent with the results from the other samples, it can be discarded as being the result of an experimental error (some step of the test procedure may have been mistakenly omitted for that sample). Most often, tests are done in duplicate or triplicate. A positive control is a procedure that is very similar to the actual experimental test but which is known from previous experience to give a positive result. A negative control is known to give a negative result. The positive control confirms that the basic conditions of the experiment were able to produce a positive result, even if none of the actual experimental samples produce a positive result. The negative control demonstrates the base-line result obtained when a test does not produce a measurable positive result; often the value of the negative control is treated as a "background" value to be subtracted from the test sample results. Sometimes the positive control takes the quadrant of a standard curve.

An example that is often used in teaching laboratories is a controlled protein assay. Students might be given a fluid sample containing an unknown (to the student) amount of protein. It is their job to correctly perform a controlled experiment in which they determine the concentration of protein in fluid sample (usually called the "unknown sample"). The teaching lab would be equipped with a protein standard solution with a known protein concentration. Students could make several positive control samples containing various dilutions of the protein standard. Negative control samples would contain all of the reagents for the protein assay but no protein. In this example, all samples are performed in duplicate. The assay is a colorimetric assay in which a spectrophotometer can measure the amount of protein in samples by detecting a colored complex formed by the interaction of protein molecules and molecules of an added dye. In the illustration, the results for the diluted test samples can be compared to the results of the standard curve (the blue line in the illustration) in order to determine an estimate of the amount of protein in the unknown sample.

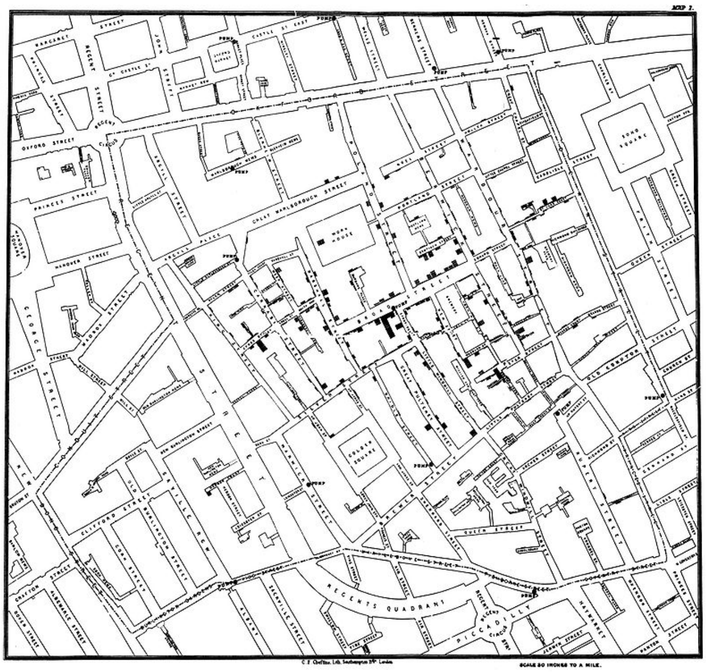
Controlled experiments can be performed when it is difficult to exactly control all the conditions in an experiment. In this case, the experiment begins by creating two or more sample groups that are *probabilistically equivalent,* which means that measurements of traits should be similar among the groups and that the groups should respond in the same manner if given the same treatment. This equivalency is determined by statistical methods that take into account the amount of variation between individuals and the number of individuals in each group. In fields such as microbiology and chemistry, where there is very little variation between individuals and the group size is easily in the millions, these statistical methods are often bypassed and simply splitting a solution into equal parts is assumed to produce identical sample groups.

Once equivalent groups have been formed, the experimenter tries to treat them identically except for the one *variable* that he or she wishes to isolate. Human experimentation requires special safeguards against outside variables such as the *placebo effect*. Such experiments are generally *double blind*, meaning that neither the volunteer nor the researcher knows which individuals are in the control group or the experimental group until after all of the data have been collected. This ensures that any effects on the volunteer are due to the treatment itself and are not a response to the knowledge that he is being treated.

In human experiments, a subject (person) may be given a stimulus to which he or she should respond. The goal of the experiment is to measure the response to a given stimulus by a test method.

Natural experiments

A **natural experiment** is an observational study in which the assignment of treatments to subjects has been haphazard: That is, the assignment of treatments to subjects has not been made by experimenters (and certainly not by randomization). Natural experiments are most useful when there has been a clearly defined and large change in the treatment (or exposure) to a clearly defined subpopulation, so that changes in responses may be plausibly attributed to the change in treatments (or exposure). Natural experiments are considered for study designs whenever controlled experimentation is difficult, such as in epidemiology and economics.



Original map by John Snow showing the clusters of cholera cases in the London epidemic of 1854

One of the most famous natural experiments was the 1854 Broad Street cholera outbreak in London, England. On 31 August 1854, a major outbreak of cholera struck Soho. Over the next three days 127 people near Broad Street died. By the end of the outbreak 616 people died. The physician John Snow identified the source of the outbreak as the nearest public water pump, which he identified using a map of deaths and illness. In this example, Snow discovered a strong association between the use of the water and deaths and illnesses due to cholera. Snow found that the water company (the Southwark and Vauxhall Company) that supplied water to districts with high attack rates obtained the water from the Thames downstream from where raw sewage was discharged into the river. By contrast, districts that were supplied water by the Lambeth Company, which obtained water upstream from the points of sewage discharge, had low attack rates. The water supply in mid-19th century London was not developed by scientists studying cholera, and so exposure to this well may be considered a haphazard event.[8] Therefore, this exposure has been recognized as being a natural experiment.[9] [10]

Field experiments

Field experiments are so named in order to draw a contrast with laboratory experiments. Often used in the social sciences, and especially in economic analyses of education and health interventions, field experiments have the advantage that outcomes are observed in a natural setting rather than in a contrived laboratory environment. However, like natural experiments, field experiments suffer from the possibility of contamination: experimental conditions can be controlled with more precision and certainty in the lab.

History

Francis Bacon

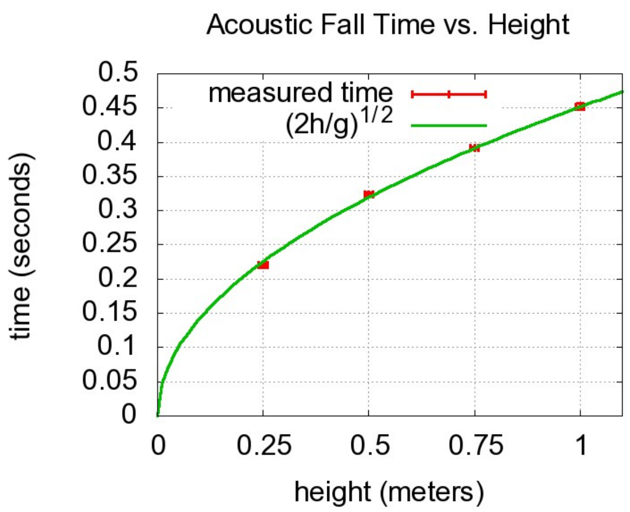
Francis Bacon was an English philosopher and scientist in the 17th century and an early and influential supporter of experimental science. He disagreed with the method of answering scientific questions by deduction and described it as follows: “Having first determined the question according to his will, man then resorts to experience, and bending her to conformity with his placets, leads her about like a captive in a procession.”[11] Bacon wanted a method that relied on repeatable observations, or experiments. He was notably the first to order the scientific method as we understand it today.

> There remains simple experience; which, if taken as it comes, is called accident, if sought for, experiment. The true method of experience first lights the candle [hypothesis], and then by means of the candle shows the way [arranges and delimits the experiment]; commencing as it does with experience duly ordered and digested, not bungling or erratic, and from it deducing axioms [theories], and from established axioms again new experiments.
>
> – Francis Bacon. *Novum Organum.* 1620.[12]

When the problem or conditions do not permit a controlled experiment, such as in astronomical research, observational studies can be useful. For example, Tycho Brahe made careful observations and recorded measurements of stellar and planetary positions over time. After Brahe's death, his measurements proved useful in the development of Johannes Kepler’s laws of planetary motion, which offered a better fit than did Ptolemy's theory.

In the centuries that followed, important advances and discoveries were made by people who applied the scientific method in different areas. For example, Galileo Galilei was able to accurately measure time and experiment to make accurate measurements and conclusions about the speed of a falling body. Antoine Lavoisier was a French chemist in the late 1700s who used experiment to describe new areas such as combustion and biochemistry and to develop the theory of conservation of mass (matter).[13] During the 1800s, Louis Pasteur used the scientific method to disprove the prevailing theory of spontaneous generation and to develop the germ theory of disease.[14] Because of the importance of controlling potentially confounding variables, the use of well-designed laboratory experiments is preferred when possible.

Galileo Galilei



Measured fall time of a small steel sphere falling from various heights. The data is in good agreement with the predicted fall time of $\sqrt{2h/g}$, where h is the height and g is the acceleration of gravity.

Galileo Galilei (1564–1642) was a scientist who performed many quantitative experiments addressing many topics. Using several different methods, Galileo was able to accurately measure time. Previously, most scientists had used distance to describe falling bodies using geometry, which had been used and trusted since Euclid.[15] Galileo himself used geometrical methods to express his results. Galileo's successes were aided by the development of a new mathematics as well as cleverly designed experiments and equipment. At that time, another kind of mathematics was being developed—algebra. Algebra allowed arithmetical calculations to become as sophisticated as geometric ones. Algebra also allowed the discoveries of scientists such as Galileo—as well as later scientists like Newton, Maxwell and Einstein—to be later summarized by mathematical equations. These equations described physical relationships in a precise, self-consistent manner.

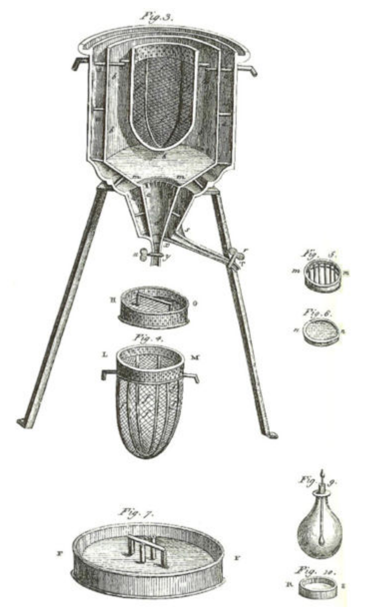
One prominent example is the "ball and ramp experiment."[16] In this experiment Galileo used an inclined plane and several steel balls of different weights. With this design, Galileo was able to slow down the falling motion and record, with reasonable accuracy, the times at which a steel ball passed certain markings on a beam.[17] Galileo disproved Aristotle's assertion that weight affects the speed of an object's fall. According to Aristotle's Theory of Falling Bodies, the heavier steel ball would reach the ground before the lighter steel ball. Galileo's hypothesis was that the two balls would reach the ground at the same time.

Other than Galileo, not many people of his day were able to accurately measure short time periods, such as the fall time of an object. Galileo accurately measured these short periods of time by creating a pulsilogon. This was a machine created to measure time using a pendulum.[18] The pendulum was synchronized to the human pulse. He used this to measure the time at which the weighted balls passed marks that he had made on the inclined plane. He measured to find that balls of different weights reached the bottom of the inclined plane at the same time and that the distance traveled was proportional to the square of the elapsed time.[19] Later scientists summarized Galileo's results as The Equation of Falling Bodies.[20] [21]

Distance *d* traveled by an object falling for time *t* where *g* is gravitational acceleration (~ 9.8 m/s^2): $d = \frac{1}{2}gt^2$

These results supported Galileo's hypothesis that objects of different weights, when measured at the same point in their fall, fall at the same speed because they experience the same gravitational acceleration.

Antoine Lavoisier



Lavoisier and Laplace's ice calorimeter device

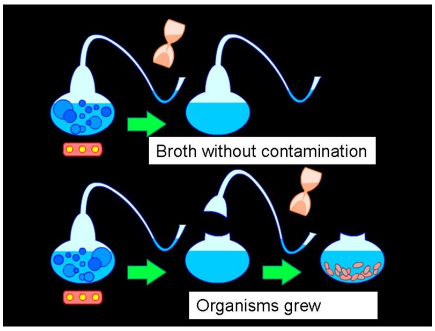
Antoine Lavoisier (1743–1794) was a French chemist regarded as the founder of modern chemistry. Lavoisier's experiments were among the first truly quantitative chemical experiments. He showed that, although matter changes its state in a chemical reaction, the quantity of matter is the same at the end as at the beginning of every chemical reaction. In one experiment, he burned phosphorus and sulfur in air to see whether the results further supported his previous conclusion (Law of Conservation of Mass). In this experiment, however, he determined that the products weighed more than the original phosphorus and sulfur. He decided to do the experiment again. This time he measured the mass of the air surrounding the experiment as well. He discovered that the mass gained in the product was lost from the air. These experiments provided further support for his Law of Conservation of Mass.

One of Lavoisier’s experiments connected the worlds of respiration and combustion. Lavoisier’s hypothesis was that combustion and respiration were one and the same, and combustion occurs with every instance of respiration. Lavoisier, working with Pierre-Simon Laplace, designed an ice calorimeter apparatus for measuring the amount of heat given off during combustion or respiration. This machine consisted of three concentric compartments. The center compartment held the source of heat, in this case, the guinea pig or piece of burning charcoal. The middle compartment held a specific amount of ice for the heat source to melt. The outside compartment contained packed snow for insulation. Lavoisier then measured the quantity of carbon dioxide and the quantity of heat produced by confining a live guinea pig in this apparatus. Lavoisier also measured the heat and carbon dioxide produced when burning a piece of charcoal in the calorimeter. Using this data, he concluded that respiration was in fact a slow combustion process. He also discovered through precise measurements that these processes produced carbon dioxide and heat with the same constant of proportionality. He found that for 224 grains of “fixed air” (CO_2) produced, 13 oz. of ice was melted in the calorimeter. Converting grains to grams and using the energy required to melt 13 oz. of ice, one can compute that for each gram of CO_2 produced, about 2.02 kcal of energy was produced by the combustion of carbon or by respiration in Lavoisier's calorimeter experiments. This compares well with the modern published heat of combustion for carbon of 2.13 kcal/g.[22] This continuous slow combustion, which Lavoisier and Laplace supposed took place in the lungs, enabled the living animal to maintain its body temperature above that of its surroundings, thus accounting for the puzzling phenomenon of animal heat.[23] Lavoisier concluded, “Lla respiration est donc une combustion," That is, respiratory gas exchange is combustion, like that of burning a candle.

Lavoisier was the first to conclude by experiment that the Law of Conservation of Mass applied to chemical change.[24] His hypothesis was that the mass of the reactants would be the same as the mass of the products in a chemical reaction. He experimented on vinous fermentation. He determined the amounts of hydrogen, oxygen, and carbon in sugar. He weighed a quantity of sugar, added yeast and water in measured amounts, and allowed the mixture to ferment. Lavoisier measured the mass of the carbonic acid gas and water that were given off during fermentation and weighed the residual liquor, the components of which were then separated and analyzed to determine their elementary composition.[25] In this way he controlled a couple of potential confounding factors. He was able to capture the carbonic acid gas and water vapor that were given off during fermentation so that his final measurements would be as accurate as possible. Lavoisier then concluded that the total mass of the reactants was equal to the mass of the final product and residue.[26] Moreover, he showed that the total mass of each constituent element before and after the chemical change remained the same. Similarly, he demonstrated via experimentation that the mass of products of combustion is equal to the mass of the reacting ingredients.

Louis Pasteur

Louis Pasteur (1822–1895), regarded as the "Father of Microbiological sciences and immunology," was a French biologist during the 19th century.[27] He discovered and supported by experimental results the idea that disease-causing agents do not spontaneously appear but are alive and need the right environment to prosper and multiply. Stemming from this discovery, he used experiment to develop vaccines for chicken cholera, anthrax and rabies, and to develop methods for reducing bacteria in some food products by heating them (pasteurization). His work also led him to advocate (along with the English physician Dr. Joseph Lister) for antiseptic surgical techniques. Most scientists of that day believed that microscopic life sprang into existence from nonliving matter. This idea was called spontaneous generation.



(Above) A swannecked flask is pictured with broth and no bacteria in it after being boiled to remove any germs or microorganisms. (Below) Another swannecked flask is pictured with outside contaminants in the air allowed in. This broth grows microorganisms.

Pasteur's observations of tiny organisms under the microscope caused him to doubt spontaneous generation. He designed an experiment to test it. His hypothesis was that life could not arise from where there is no life. He took care to control possible confounding factors. For example, he needed to make sure there was no life, even microscopic, in the flasks of broth he used as a test medium. He decided to kill any microscopic organisms already present by boiling the broth until he was confident that any microorganisms present were killed. Pasteur also needed to make sure that no microscopic organisms entered the broth after boiling, yet the broth needed exposure to air to properly test the theory. A colleague suggested a flask with a neck the shape of an "S" turned sideways. Dust (which Pasteur thought contained microorganisms) would be trapped at the bottom of the first curve, but the air would flow freely through.[28]

Thus, if bacteria should really be spontaneously generated, then they should be growing in the flask after a few days. If spontaneous generation did not occur, then the contents of the flasks would remain lifeless. In the end, it was a complete success; not a single microorganism appeared in the broth. Then Pasteur allowed the dust containing the microorganisms to mix with the broth. In just a few days the broth became cloudy from millions of organisms growing in it. For two more years, he repeated the experiment in various conditions and locales to assure himself that the results were correct. In this way Pasteur supported his hypothesis that spontaneous generation does not occur.[29] Despite the experimental results supporting his hypotheses and his success curing or preventing various diseases, correcting the public misconception of spontaneous generation was a slow, difficult process.

As he worked to solve specific problems, Pasteur's notions were sometimes corrected by the results of his experiments, such as when he was asked to find the cause of disease devastating the French silkworm industry in 1865. After a year of diligent work he correctly identified a culprit organism and gave practical advice for developing a healthy population of moths. However, when he tested his own advice, he found disease still present. It turned out he had been correct but incomplete – there were two organisms at work. It took two more years of experimenting to find the complete solution.[30]

Observational science

Observational science is used when it is impractical to fit a system into a laboratory setting. It can also be used when confounding factors are either limited or known well enough to analyze the data in light of them. In order for an observational science to be valid, the confounding factors must be known and accounted for.

Astronomy

An early European observational scientist was Tycho Brahe (1546–1601). Brahe’s observations of stellar and planetary positions were noteworthy both for their accuracy and quantity.[31] His celestial positions were much more accurate than those of any predecessor or contemporary. In an observatory funded for him by King Frederick II of Denmark, Brahe built some of the largest observing instruments yet constructed.[32] Because of the large size of this equipment, Brahe was able to measure angles to an accuracy of better than 0.1 degree.[33] This was more accurate than any previous observations and close to the limit that the human eye can observe.[33] In this way, Brahe was able to make observations about stellar and planetary positions in a lab setup.

Brahe himself was not a Copernican but proposed a system in which the Sun and Moon orbited the Earth, while the other planets orbited the Sun. His system provided a safe position for astronomers who were dissatisfied with older models but were reluctant to accept the Earth's motion. It gained a considerable following after 1616 when Rome decided officially that the heliocentric model was contrary to both philosophy and Scripture, and could be discussed only as a computational convenience that had no connection to fact. His system also offered a major innovation: while both the geocentric model and the heliocentric model as set forth by Copernicus relied on the idea of transparent rotating crystalline spheres to carry the planets in their orbits, Brahe eliminated the spheres entirely.

Johannes Kepler (1571–1630) used the accurate observations of Brahe to discover the shape of Mars’ orbit. His first hypothesis was that the orbit was circular. After four years of research and testing 70 different combinations of circles and epicycles, he devised a shape that would fit Mars’ orbit. However, the model was accurate to only 0.13 degrees.[34] Kepler knew that Brahe’s observations could be used to develop an orbit shape more accurate than this. Kepler eventually decided to try various oval shaped orbits. This implied that the speed of the planet changed as it traveled around the oval. After nine years, he found that elliptical orbits fit satisfactorily with the observed path of Mars. He found that this shape worked not only for Mars, but also for every planet that Brahe had observed.[34]

Biology

Observational studies are not experiments. By definition, observational studies lack the manipulation required for Baconian experiments. In addition, observational studies in biological systems often involve variables that are challenges to quantify or control. Nevertheless, observational studies are used because it is sometimes too difficult (too expensive, or too much time required) or unethical to conduct longitudinal experiments with human or animal subjects. In these situations, observational studies have value because they often suggest hypotheses that can be tested with randomized experiments or by collecting fresh data.

In providing therapies for human subjects, for example in psychology or health care, it is unethical to provide a substandard treatment to patients. Therefore, ethical review boards are supposed to stop clinical trials and other experiments unless a new treatment is believed to offer benefits as good as current best practice.[35] It is also unethical and often illegal to conduct randomized experiments on the effects of substandard or harmful treatments, such as the effects of ingesting arsenic on human health. To understand the effects of such exposures, scientists use observational studies.

Observational studies are limited because they lack the statistical properties of randomized experiments. In a randomized experiment, the method of randomization specified in the experimental protocol guides the statistical analysis, which is usually specified also by the experimental protocol.[36] Without a statistical model that reflects an objective randomization, the statistical analysis relies on a subjective model.[36] Inferences from subjective models are unreliable in theory and practice.[37] In fact, there are several cases where carefully conducted observational studies consistently give wrong results, that is, where the results of the observational studies are inconsistent and also differ from the results of experiments. For example, epidemiological studies of colon cancer consistently show beneficial correlations with broccoli consumption, while experiments find no benefit.[38]

A particular problem with observational studies involving human subjects is the great difficulty attaining fair comparisons between treatments (or exposures), because such studies are prone to selection bias, and groups receiving different treatments (exposures) may differ greatly according to their covariates (age, height, weight, medications, exercise, nutritional status, ethnicity, family medical history, etc.). In contrast, randomization implies that for each covariate, the mean for each group is expected to be the same. For any randomized trial, some variation from the mean is expected, of course, but the randomization ensures that the experimental groups have mean values that are close, due to the central limit theorem and Markov's inequality. With poor randomization, the systematic variation in covariates between the treatment groups (or exposure groups) makes it difficult to separate the effect of the treatment (exposure) from the effects of the other covariates, most of which have not been measured. The mathematical models used to analyze such data must consider each differing covariate (if measured), and the results will not be meaningful if a covariate is neither randomized nor included in the model.

To avoid these conditions that render an experiment far less useful, physicians conducting medical trials (such as for Food and Drug Administration approval), will quantify and randomize the covariates that can be identified. Researchers attempt to reduce the biases of observational studies with complicated statistical methods such as propensity score matching methods, which require large populations of subjects and extensive information on covariates. Outcomes are also quantified when possible (bone density, amount of some cell or substance in the blood, physical strength or endurance, etc.) and not based on a subject's or a professional observer's opinion. In this way, the design of an observational study can render the results more objective and therefore more convincing.

See also hierarchy of evidence and quasi-empirical methods.

See also

- Design of experiments
- Experimental physics
- Experimetrics : application of econometrics to economics experiments.
- List of experiments
- Long-term experiment
- True experiment

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In stopping the use of water from the well-pump, the authorities did an uncontrolled experiment (without a control group) and without randomization.

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External links

- Lessons In Electric Circuits - Volume VI - Experiments (http://www.electriccircuits.net/book,6,experiments.aspx)
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Falsifiability

Falsifiability or **refutability** is the logical possibility that an assertion could be shown false by a particular observation or physical experiment. That something is "falsifiable" does not mean it is false; rather, it means that *if* the statement were false, then its falsehood could be demonstrated.


"All swans are white" is a falsifiable claim - it *could* be proven wrong.

The claim "No human lives forever" is not falsifiable since it does not seem possible to prove wrong. In theory, one would have to observe a human living *forever* to falsify that claim. On the other hand, "All humans live forever" is falsifiable since the presentation of just one dead human could prove the statement wrong (excluding metaphysical assertions about souls, which are not falsifiable). Moreover, a claim may be true and still be falsifiable; if "All humans live forever" we will never actually find a dead human, and yet that claim would still be falsifiable because we can at least *imagine* the observation that would prove it wrong.

Some statements are only falsifiable in theory, while others are even falsifiable in practice (i.e. testable). For example, "it will be raining here in one billion years" is theoretically falsifiable, but not practically so.

Falsifiability, particularly testability, is an important concept in science and the philosophy of science. The concept was made popular by Karl Popper in his philosophical analysis of the scientific method. Popper concluded that a hypothesis, proposition, or theory is "scientific" only if it is, among other things, falsifiable. That is, falsifiability is a necessary (but not sufficient) criterion for scientific ideas. Popper asserted that unfalsifiable statements are non-scientific, although not without relevance. For example, meta-physical or religious propositions have cultural or spiritual meaning, and the ancient metaphysical and unfalsifiable idea of the existence of atoms has led to corresponding falsifiable modern theories. A falsifiable theory that has withstood severe scientific testing is said to be corroborated by past experience, though in Popper's view this is not equivalent with confirmation and does not guarantee that the theory is true or even partially true.

Popper invented the notion of metaphysical research programs to name such ideas. In contrast to positivism, which held that statements are senseless if they cannot be verified or falsified, Popper claimed that falsifiability is merely a special case of the more general notion of criticizability. Still, he admitted that tests and refutation is one of the most effective methods by which theories can be criticized.

Naïve falsification

Two types of statements: observational and categorical

In work beginning in the 1930s, Popper gave falsifiability a renewed emphasis as a criterion of empirical statements in science.

Popper noticed that two types of statements are of particular value to scientists.

The first are statements of observations, such as "this is a white swan." Logicians call these statements singular existential statements, since they assert the existence of some particular thing. They are equivalent to a propositional calculus statement of the form: *There exists an x such that x is a swan, and x is white*.

The second are statements that categorize all instances of something, such as "all swans are white". Logicians call these statements universal. They are usually parsed in the form: *For all x, if x is a swan, then x is white*. Scientific laws are commonly supposed to be of this type. One difficult question in the methodology of science is: How does one move from observations to laws? How can one validly infer a universal statement from any number of existential statements?

Inductivist methodology supposed that one can somehow move from a series of singular existential statements to a universal statement. That is, that one can move from 'this is a white swan', 'that is a white swan', and so on, to a universal statement such as 'all swans are white'. This method is clearly *deductively* invalid, since it is always possible that there may be a non-white swan that has eluded observation (and, in fact, the discovery of the Australian black swan demonstrated the deductive invalidity of this particular statement).

Inductive categorical inference

Popper held that science could not be grounded on such an invalid inference. He proposed falsification as a solution to the problem of induction. Popper noticed that although a singular existential statement such as 'there is a white swan' cannot be used to affirm a universal statement, it can be used to show that one is false: the singular existential observation of a black swan serves to show that the universal statement 'all swans are white' is false—in logic this is called modus tollens. 'There is a black swan' implies 'there is a non-white swan,' which, in turn, implies 'there is something that is a swan and that is not white', hence 'all swans are white' is false, because that is the same as 'there is *nothing* that is a swan and that is not white'.

One notices a white swan. From this one can conclude:

> At least one swan is white.

From this, one may wish to conjecture:

> All swans are white.

It is impractical to observe all the swans in the world to verify that they are all white.

Even so, the statement *all swans are white* is testable by being falsifiable. For, if in testing many swans, the researcher finds a single black swan, then the statement *all swans are white* would be falsified by the counterexample of the single black swan.

Deductive falsification

Deductive falsification is different from an absence of verification. The falsification of statements occurs through modus tollens, via some observation. Suppose some universal statement *U* forbids some observation *O*:

$$U \rightarrow \neg O$$

Observation O, however, is made:

$$O$$

So by modus tollens,

$$\neg U$$

Although the logic of naïve falsification is valid, it is rather limited. Nearly any statement can be made to fit the data, so long as one makes the requisite 'compensatory adjustments'. Popper drew attention to these limitations in *The Logic of Scientific Discovery* in response to criticism from Pierre Duhem. W. V. Quine expounded this argument in detail, calling it confirmation holism. To logically falsify a universal, one must find a true falsifying singular statement. But Popper pointed out that it is always possible to *change* the universal statement or the existential statement so that falsification does not occur. On hearing that a black swan has been observed in Australia, one might introduce the ad hoc hypothesis, 'all swans are white except those found in Australia'; or one might adopt another, more cynical view about some observers, 'Australian bird watchers are incompetent'.

Thus, naïve falsification ought to, but does not, supply a way of handling competing hypotheses for many subject controversies (for instance conspiracy theories and urban legends). People arguing that there is no support for such an observation may argue that there is nothing to see, that all is normal, or that the differences or appearances are too small to be statistically significant. On the other side are those who concede that an observation has occurred and that a universal statement has been falsified as a consequence. Therefore, naïve falsification does not enable scientists, who rely on objective criteria, to present a definitive falsification of universal statements.

Falsificationism

Naïve falsificationism is an unsuccessful attempt to prescribe a rationally unavoidable method for science. Sophisticated methodological falsification, on the other hand, is a prescription of a way in which scientists ought to behave as a matter of choice. The object of this is to arrive at an evolutionary process whereby theories become *less bad*.

Naïve falsification considers scientific statements individually. Scientific theories are formed from groups of these sorts of statements, and it is these groups that must be accepted or rejected by scientists. Scientific theories can always be defended by the addition of ad hoc hypotheses. As Popper put it, a *decision* is required on the part of the scientist to accept or reject the statements that go to make up a theory or that might falsify it. At some point, the weight of the ad hoc hypotheses and disregarded falsifying observations will become so great that it becomes unreasonable to support the base theory any longer, and a decision will be made to reject it.

In place of naïve falsification, Popper envisioned science as evolving by the successive rejection of falsified theories, rather than falsified statements. Falsified theories are to be replaced by theories that can account for the phenomena that falsified the prior theory, that is, with greater explanatory power. For example, Aristotelian mechanics explained observations of everyday situations, but were falsified by Galileo’s experiments, and were replaced by Newtonian mechanics, which accounted for the phenomena noted by Galileo (and others). Newtonian mechanics' reach included the observed motion of the planets and the mechanics of gases. Or at least most of them; the size of the precession of the orbit of Mercury was not predicted by Newtonian mechanics, but was by Einstein's general relativity. The Youngian wave theory of light (i.e., waves carried by the luminiferous aether) replaced Newton's (and many of the Classical Greeks') particles of light but in turn was falsified by the Michelson-Morley experiment and was superseded by Maxwell's electrodynamics and Einstein's special relativity, which did account for the newly observed phenomena. Furthermore, Newtonian mechanics applied to the atomic scale was replaced with quantum mechanics, when the old theory could not provide an answer to the ultraviolet catastrophe, the Gibbs paradox, or how electron orbits could exist without the particles radiating away their energy and spiraling towards the centre. Thus the new theory had to posit the existence of unintuitive concepts such as energy levels, quanta and Heisenberg's uncertainty principle.

At each stage, experimental observation made a theory untenable (i.e., falsified it) and a new theory was found that had greater *explanatory power* (i.e., could account for the previously unexplained phenomena), and as a result, *provided greater opportunity for its own falsification*.

The criterion of demarcation

Popper uses falsification as a criterion of demarcation to draw a sharp line between those theories that are scientific and those that are unscientific. It is useful to know if a statement or theory is falsifiable, if for no other reason than that it provides us with an understanding of the ways in which one might assess the theory. One might at the least be saved from attempting to falsify a non-falsifiable theory, or come to see an unfalsifiable theory as unsupportable.

Popper claimed that, if a theory is falsifiable, then it is scientific.

The Popperian criterion excludes from the domain of science not unfalsifiable *statements* but only *whole theories* that *contain no* falsifiable statements; thus it leaves us with the Duhemian problem of what constitutes a 'whole theory' as well as the problem of what makes a statement 'meaningful'. Popper's own falsificationism, thus, is not only an alternative to verificationism, it is also an acknowledgement of the conceptual distinction that previous theories had ignored.

Verificationism

In the philosophy of science, verificationism (also known as the verifiability theory of meaning) holds that a statement must, in principle, be empirically verifiable for it to be both meaningful and scientific. This was an essential feature of the logical positivism of the so-called Vienna Circle that included such philosophers as Moritz Schlick, Rudolf Carnap, Otto Neurath, the Berlin philosopher Hans Reichenbach, and the logical empiricism of A.J. Ayer.

Popper noticed that the philosophers of the Vienna Circle had mixed two different problems, that of meaning and that of demarcation, and had proposed in verificationism a single solution to both. In opposition to this view, Popper emphasized that there are meaningful theories that are not scientific, and that, accordingly, a criterion of meaningfulness does not coincide with a criterion of demarcation.

Thus, Popper urged that verifiability be replaced with falsifiability as the criterion of demarcation. On the other hand, he strictly opposed the view that non-falsifiable statements are meaningless or otherwise inherently bad, and noted that falsificationism does not imply it.[1]

Use in courts of law

Falsifiability was one of the criteria used by Judge William Overton in the McLean v. Arkansas ruling to determine that 'creation science' was not scientific and should not be taught in Arkansas public schools. In his conclusion related to this criterion he stated that "While anybody is free to approach a scientific inquiry in any fashion they choose, they cannot properly describe the methodology as scientific, if they start with the conclusion and refuse to change it regardless of the evidence developed during the course of the investigation."[2]

It was also enshrined in United States law as part of the Daubert Standard set by the Supreme Court for whether scientific evidence is admissible in a jury trial.

Criticisms

Contemporary philosophers

Many contemporary philosophers of science and analytic philosophers are strongly critical of Popper's philosophy of science . Popper's mistrust of inductive reasoning has led to claims that he misrepresents scientific practice. Among the professional philosophers of science, the Popperian view has never been seriously preferred to probabilistic induction, which is the mainstream account of scientific reasoning.[3] Adherents of Popper speak with disrespect of "professional philosophy", for example W. W. Bartley:

> Sir Karl Popper is not really a participant in the contemporary professional philosophical dialogue; quite the contrary, he has ruined that dialogue. If he is on the right track, then the majority of professional philosophers the world over have wasted or are wasting their intellectual careers. The gulf between Popper's way of doing philosophy and that of the bulk of contemporary professional philosophers is as great as that between astronomy and astrology.[4]

Rafe Champion:

> Popper's ideas have failed to convince the majority of professional philosophers because his theory of conjectural knowledge does not even pretend to provide positively justified foundations of belief. Nobody else does better, but they keep trying, like chemists still in search of the Philosopher's Stone or physicists trying to build perpetual motion machines.[5]

and David Miller:

> What distinguishes science from all other human endeavours is that the accounts of the world that our best, mature sciences deliver are strongly supported by evidence and this evidence gives us the strongest reason to believe them.' That anyway is what is said at the beginning of the advertisement for a recent conference on induction at a celebrated seat of learning in the UK. It shows how much critical rationalists still have to do to make known the message of *Logik der Forschung* concerning what empirical evidence is able to do and what it does.[6]

Kuhn and Lakatos

Whereas Popper was concerned in the main with the *logic* of science, Thomas Kuhn's influential book *The Structure of Scientific Revolutions* examined in detail the history of science. Kuhn argued that scientists work within a conceptual paradigm that strongly influences the way in which they see data. Scientists will go to great length to defend their paradigm against falsification, by the addition of *ad hoc* hypotheses to existing theories. Changing a 'paradigm' is difficult, as it requires an individual scientist to break with his or her peers and defend a heterodox theory.

Some falsificationists saw Kuhn's work as a vindication, since it provided historical evidence that science progressed by rejecting inadequate theories, and that it is the *decision*, on the part of the scientist, to accept or reject a theory that is the crucial element of falsificationism. Foremost amongst these was Imre Lakatos.

Lakatos attempted to explain Kuhn's work by arguing that science progresses by the falsification of *research programs* rather than the more specific universal statements of naïve falsification. In Lakatos' approach, a scientist works within a research program that corresponds roughly with Kuhn's 'paradigm'. Whereas Popper rejected the use of *ad hoc* hypotheses as unscientific, Lakatos accepted their place in the development of new theories.

Some philosophers of science, such as Paul Feyerabend, take Kuhn's work as showing that social factors, rather than adherence to a purely rational method, decide which scientific theories gain general acceptance. Many other philosophers of science dispute such a view, such as Alan Sokal and Kuhn himself.

Feyerabend

Paul Feyerabend examined the history of science with a more critical eye, and ultimately rejected any prescriptive methodology at all. He rejected Lakatos' argument for ad hoc hypothesis, arguing that science would not have progressed without making use of any and all available methods to support new theories. He rejected any reliance on a scientific method, along with any special authority for science that might derive from such a method. Rather, he claimed that if one is keen to have a universally valid methodological rule, epistemological anarchism or *anything goes* would be the only candidate. For Feyerabend, any special status that science might have derives from the social and physical value of the results of science rather than its method.

Sokal and Bricmont

In their book *Fashionable Nonsense* (published in the UK as *Intellectual Impostures*) the physicists Alan Sokal and Jean Bricmont criticized falsifiability on the grounds that it does not accurately describe the way science really works. They argue that theories are used because of their successes, not because of the failures of other theories. Their discussion of Popper, falsifiability and the philosophy of science comes in a chapter entitled "Intermezzo," which contains an attempt to make clear their own views of what constitutes truth, in contrast with the extreme epistemological relativism of postmodernism.

Sokal and Bricmont write, "When a theory successfully withstands an attempt at falsification, a scientist will, quite naturally, consider the theory to be partially confirmed and will accord it a greater likelihood or a higher subjective probability. ... But Popper will have none of this: throughout his life he was a stubborn opponent of any idea of 'confirmation' of a theory, or even of its 'probability'. ... [but] the history of science teaches us that scientific theories come to be accepted above all because of their successes." (Sokal and Bricmont 1997, 62f)

They further argue that falsifiability cannot distinguish between astrology and astronomy, as both make technical predictions that are sometimes incorrect.

David Miller, a contemporary philosopher of critical rationalism, has attempted to defend Popper against these claims.[7]

Examples

Claims about verifiability and falsifiability have been used to criticize various controversial views. Examining these examples shows the usefulness of falsifiability by showing us where to look when attempting to criticise a theory.

Non-falsifiable theories can usually be reduced to a simple uncircumscribed existential statement, such as *there exists a green swan*. It is entirely possible to *verify* whether or not this statement is true, simply by producing the green swan. But since this statement does not specify when or where the green swan exists; it is simply not possible to show that the swan does not exist, and so it is impossible to *falsify* the statement. That such theories are unfalsifiable says nothing about either their validity or truth. But it does assist us in determining to what extent such statements might be evaluated. If evidence cannot be presented to support a case, and yet the case cannot be shown to be indeed false, not much credence can be given to such a statement. However, you can also look at this case from another perspective. Let's say that the statement is "all swans are not green". An attempt to *verify* this positively would require a search for non-green swans, which you are sure to find. However, having rounded up and examined every known swan, there is always the possibility that there is at least one more swan but we will never know for sure until we find it and if we do, there may be yet, one more swan, and it may be green. On the other hand, we may say that "all swans are not green" but instead of attempting to positively verify this statement we attempt to falsify it by looking for a green swan. In that case, we need only find one swan (a green one), in the absence of which we can accept the original statement as a working hypothesis until such a swan is discovered.

Economics

Aspects of economics have been accused of not being falsifiable, mainly by sociologists and other social scientists in general.

The most common argument is made against rational expectations theories, which work under the assumption that people act to maximize their utility. However, under this viewpoint, it is impossible to disprove the fundamental theory that people are utility-maximizers. The political scientist Graham T. Allison, in his book *Essence of Decision*, attempted to both quash this theory and substitute other possible models of behavior.

Another construct that has been accused of being irrefutable is the principle of comparative advantage[8]

Ethics

Ethical statements such as "murder is evil" or "it is good to help those in need" are not usually considered to be falsifiable. This does not necessarily amount to conclusion that they are all false, or without truth-values. It mainly affects their status as scientific theories. The meta-ethical thesis that ethical statements have no truth-value is called non-cognitivism.

Evolution

Numerous examples of potential (indirect) ways to falsify common descent have been proposed by evolutionists. J.B.S. Haldane, when asked what hypothetical evidence could disprove evolution, replied "fossil rabbits in the Precambrian era"[9] . Richard Dawkins adds that any other modern animals, such as a hippo, would suffice.[10] [11] [12]

Karl Popper at first spoke against the testability of natural selection [13] [14] but later recanted, "I have changed my mind about the testability and logical status of the theory of natural selection, and I am glad to have the opportunity to make a recantation."[15]

Historicism

Theories of history or politics that allegedly predict future events have a logical form that renders them neither falsifiable nor verifiable. They claim that for every historically significant event, there exists an historical or economic law that *determines* the way in which events proceeded. Failure to identify the law does not mean that it does not exist, yet an event that satisfies the law does not prove the general case. Evaluation of such claims is at best difficult. On this basis, Popper "fundamentally criticized historicism in the sense of any preordained prediction of history"[16] , and argued that neither Marxism nor psychoanalysis was science [16] , although both made such claims. Again, this does not mean that any of these types of theories is necessarily *incorrect*. Popper considered falsifiability a test of whether theories are scientific, not of whether propositions that they contain or support are true.

Logic and mathematics

The question may be raised as to whether the theorems of logic and mathematics are falsifiable or not. In considering this question, it is helpful to introduce a classical distinction that is frequently emphasized in this connection by Charles Sanders Peirce. On the one hand, he defines a *positive science* as "an inquiry which seeks for *positive* knowledge", that is, for knowledge that can be expressed in a *categorical proposition* (Peirce, *The Essential Peirce* (EP) v. 2, 144). He goes on to say the following of the normative sciences, namely, logic, ethics and aesthetics:

> Logic and the other normative framework ask not what *is* but what *ought to be*. They are nevertheless positive sciences since it is by asserting positive, categorical truth that they are able show that what really is so; and the right reason derived from positive categorical fact. (Peirce, EP 2, 144).

On the other hand, Peirce distinguishes mathematics proper from all positive sciences, and reckons it more fundamental than any of them, saying that any positive science "must, if it is to be properly grounded, be made to depend upon the Conditional or Hypothetical Science of *Pure Mathematics*, whose only aim is to discover not how things actually are, but how they might be supposed to be, if not in our universe, then in some other" (Peirce, EP 2, 144).

In this way of looking at things, logic is a science that seeks after knowledge of how we ought to conduct our reasoning if we want to achieve the goals of reasoning. As such, the logical knowledge that we have at any given time can easily fall short of perfection. However, the laws of logic themselves (the rules of inference and logical axioms) are not subject to falsifiability per se. That is, since truth values are defined in relation to the laws of logic any "falsification" of these laws would represent a self-contradictory situation though this conclusion has been argued against by philosophers such as W.V. Quine.

Pure mathematics, on the contrary, contains no propositions that are not contingent on prior assumptions. Its apparent certainty is but a relative certainty, relative to the certainty of its axioms. One can say that its theorems are tautologies, so long as one remembers the original meaning of tautology, which is a repetition of something previously asserted. Mathematical theorems merely say more acutely what the axioms more obtusely already say.

Applied mathematics, in particular, mathematics as applied in empirical science, is still more generalized. The application of mathematical abstractions to a domain of experiential phenomena involves a critical comparison of many different mathematical models, not all of them consistent with each other, and it normally leads to a judgment that some of the hypothetical models are better analogues or more likely icons than others of the empirical domain in question. This is, of course, an extremely fallible business, and each judgment call is subject to revision as more empirical data comes in.

How well a mathematical formula applies to the physical world is a physical question, and thus testable, within certain limits. For example, the proposition that all objects follow a parabolic path when thrown into the air is falsifiable; indeed, it is false. To see this, one has but to think of a feather. A slightly better proposition is that all objects follow a parabolic path when thrown in a vacuum and acted upon by gravity, which is itself falsified in regard to paths whose lengths are not negligible in proportion to a given planet's radius (or equivalently if the path is in a non-uniform gravitational field).

What is the conclusion then? Are mathematical theorems falsifiable or not? The most that can be said of them is that they are true of what they are true of, but what they are true of may not be the object of a given experience.

The above discussion addressed the nature of mathematical theorems in and of themselves, and then took up their application to empirical phenomena. But the actual practice of mathematics involves yet another level of consideration, and it may yet involve activities that are very similar to empirical science. Many working mathematicians, from Peirce in his day to Stephen Wolfram in ours, have remarked on the active, observational, and even experimental character of mathematical work. Imre Lakatos brings the concept of falsifiability to bear on the discipline of mathematics in his *Proofs and Refutations*. The question of whether mathematical practice is a quasi-experimental science depends in part on whether proofs are fundamentally different from experiments. Lakatos argues that often axioms, definitions, and proofs evolve through criticism and counterexample in a manner not unlike the way that a scientific theory evolves in response to experiments.

Solipsism

Metaphysical solipsism is the view that the individual self of the solipsistic philosopher is the whole of reality and that the external world and other persons are representations of that self having no independent existence (Wood, p. 295). Metaphysical solipsism is not empirically falsifiable because once one has taken the solipsistic position, any evidence that might establish an external world is already viewed as being within (or produced by) the self. However, expressions of solipsism may be self-refuting.

Anti-solipsism—the position that an external world does exist—is similarly non-falsifiable because regardless of what evidence is produced, it is always possible that there exists an external world outside one's experiences that does not interact with them.

Theism

Some, but not all notions of a God are unfalsifiable. The transcendental quality of omnipotence(all powerful) is impossible to prove wrong, for instance. The idea of an omnipotent being is unfalsifiable: there is no observation that could not be his/her creation (of course, whether this is relevant to justifying the existence of God might be debated). Certain other claims are falsifiable or even empirically testable. Cases in point include some miracles or the hypothesis that God created humankind specifically in their modern form, which was falsified by evidence that instead supports evolutionary origins from some common ancestor. Other beliefs have been falsified as scientific understanding has increased, or in some cases as science has gathered evidence of absence.

Quotations

- Albert Einstein is reported to have said: *No amount of experimentation can ever prove me right; a single experiment can prove me wrong.* (paraphrased)[17] [18] [19]
- *The criterion of the scientific status of a theory is its falsifiability, or refutability, or testability.* — Karl Popper, (Popper, CR, 36)

Notes

[1] *Logic of Scientific Discovery*, section 6, footnote *3
[2] McLean v. Arkansas Board of Education (http://www.talkorigins.org/faqs/mclean-v-arkansas.html), Decision January 5, 1982.
[3] Confirmation, Induction and Science (http://www.lse.ac.uk/collections/CPNSS/events/Conferences/ConfirmationInductionandScience/Confirmation2007.htm)
[4] W. W. Bartley, III: Biology & evolutionary epistemology. *Philosophia* **6**:3–4 (September–December 1976), pp. 463–494
[5] Rafe Champion: Agreeing to Disagree: Bartley's Critique of Reason (http://www.the-rathouse.com/bartagree.html). *Melbourne Age Monthly Review* (October 1985)
[6] David Miller: Some hard questions for critical rationalism
[7] Miller, David (2000). "Sokal and Bricmont: Back to the Frying Pan" (http://www2.warwick.ac.uk/fac/soc/philosophy/staff/miller/miller_pli_9.pdf). *Pli* **9**: 156–73. ., also chapter 6 of Miller, David (2006). *Out of Error*. Ashgate.
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[16] Burton, Dawn (2000). *Research training for social scientists: a handbook for postgraduate researchers* (http://books.google.com/books?id=ibePpZ-6lkgC&pg=PA12). SAGE. pp. 12–13. ISBN 0-761-96351-0. .,
[17] Calaprice, Alice (2005). *The New Quotable Einstein*. USA: Princeton University Press and Hebrew University of Jerusalem. pp. 291. ISBN 0-691-12074-9.Calaprice denotes this not as an exact quotation, but as a paraphrase of a translation of A. Einstein's "Induction and Deduction". *Collected Papers of Albert Einstein* Vol. 7, Document 28. *The Berlin Years: Writings, 1918-1921*. A. Einstein; M. Janssen, R. Schulmann, et al., eds.
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See also

- Closed circle
- Cognitive bias
- Contingency
- Defeasible reasoning
- Demarcation problem
- Duhem–Quine thesis
- Fallibilism
- Hypothetico-deductive model
- Inquiry
- Interpretive science
- Logical positivism
- Metaphysical solipsism
- Methodological solipsism
- Not even wrong
- Occam's razor
- Philosophy of mathematics
- Philosophy of science
- Pragmatic maxim
- Precambrian rabbit
- Predictive power
- Reproducibility
- Scientific method
- Superseded scientific theory
- Tautology
- Testability
- Theory-ladenness

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External links

- Problems with Falsificationism (http://www.galilean-library.org/falsificationism.html) at The Galilean Library

Feeling

Feeling is the nominalization of "to feel". The word was first used in the English language to describe the physical sensation of touch through either experience or perception. The word is also used to describe experiences, other than the physical sensation of touch, such as "a feeling of warmth".[1] In psychology, the word is usually reserved for the conscious subjective experience of emotion.[2] Phenomenology and heterophenomenology are philosophical approaches that provide some basis for knowledge of feelings. Many schools of psychotherapy depend on the therapist achieving some kind of understanding of the client's feelings, for which methodologies exist. Some theories of interpersonal relationships also have a role for shared feelings or understanding of another person's feelings.


Sensitive, sculpture by Miquel Blay (1910)

Perception of the physical world does not necessarily result in a universal reaction among receivers (see emotions), but varies depending on one's tendency to handle the situation, how the situation relates to the receiver's past experiences, and any number of other factors. Feelings are also known as a state of consciousness, such as that resulting from emotions, sentiments or desires.

Gut feeling

A gut feeling, or gut reaction, is a visceral emotional reaction to something, and often one of uneasiness. Gut feelings are generally regarded as not modulated by conscious thought, and as a reflection of intuition rather than rationality.

The phrase "gut feeling" may also be used as a short-hand term for an individual's "common sense" perception of what is considered "the right thing to do"; such as: helping an injured passerby, avoiding dark alleys and generally acting in accordance with instinctive feelings about a given situation. It can also refer to simple common knowledge phrases which are true no matter when said, such as "Water is wet", "Fire is hot", or to ideas that an individual intuitively regards as true, without proof (see "Truthiness" for examples).

Gut feelings, like all reflexive unconscious comparisons, can be re-programmed by practice or experience.

See also

- Affect or Affective
- Feelings
- Emotion
- Feeling rules
- Intuition
- The Rational Feeling Function in Jung's Psychological Types
- Myers-Briggs Type Indicator
- Qualia
- Haptics (disambiguation)
- Vedanā, the Buddhist concept of feeling
- Wiktionary: intuition

- Wiktionary: qualia
- Wiktionary: touch

Footnotes

[1] feeling - Dictionary definition and pronunciation - Yahoo! Education (http://education.yahoo.com/reference/dictionary/entry/feeling)
[2] VandenBos, Gary (2006) *APA Dictionary of Psychology*. Washington, DC: American Psychological Association

External links

- A Dictionary of Feelings (http://www.feelingdictionary.com)

Hypothesis

A **hypothesis** (from Greek *ὑπόθεσις*; plural **hypotheses**) is a proposed explanation for an observable phenomenon. The term derives from the Greek, *ὑποτιθέναι* – *hypotithenai* meaning "to put under" or "to suppose." For a hypothesis to be put forward as a **scientific hypothesis**, the scientific method requires that one can test it. Scientists generally base scientific hypotheses on previous observations that cannot satisfactorily be explained with the available scientific theories. Even though the words "hypothesis" and "theory" are often used synonymously in common and informal usage, a scientific *hypothesis* is not the same as a scientific *theory*. A working hypothesis is a provisionally accepted hypothesis.

In a related but distinguishable usage, the term **hypothesis** is used for the antecedent of a proposition; thus in proposition "If *P*, then *Q*", *P* denotes the hypothesis (or antecedent); *Q* can be called a consequent. *P* is the assumption in a (possibly counterfactual) *What If* question.

The adjective **hypothetical**, meaning "having the nature of a hypothesis," or "being assumed to exist as an immediate consequence of a hypothesis," can refer to any of these meanings of the term "hypothesis."

In its ancient usage, hypothesis also refers to a summary of the plot of a classical drama.

Uses

In Plato's *Meno* (86e–87b), Socrates dissects virtue with a method used by mathematicians,[1] that of "investigating from a hypothesis."[2] In this sense, 'hypothesis' refers to a clever idea or to a convenient mathematical approach that simplifies cumbersome calculations.[3] Cardinal Bellarmine gave a famous example of this usage in the warning issued to Galileo in the early 17th century: that he must not treat the motion of the Earth as a reality, but merely as a hypothesis.[4]

In common usage in the 21st century, a *hypothesis* refers to a provisional idea whose merit requires evaluation. For proper evaluation, the framer of a hypothesis needs to define specifics in operational terms. A hypothesis requires more work by the researcher in order to either confirm or disprove it. In due course, a confirmed hypothesis may become part of a theory or occasionally may grow to become a theory itself. Normally, scientific hypotheses have the form of a mathematical model. Sometimes, but not always, one can also formulate them as existential statements, stating that some particular instance of the phenomenon under examination has some characteristic and causal explanations, which have the general form of universal statements, stating that every instance of the phenomenon has a particular characteristic.

Any useful hypothesis will enable predictions by reasoning (including deductive reasoning). It might predict the outcome of an experiment in a laboratory setting or the observation of a phenomenon in nature. The prediction may also invoke statistics and only talk about probabilities. Karl Popper, following others, has argued that a hypothesis must be falsifiable, and that one cannot regard a proposition or theory as scientific if it does not admit the possibility of shown false. Other philosophers of science have rejected the criterion of falsifiability or supplemented it with other criteria, such as verifiability (e.g., verificationism) or coherence (e.g., confirmation holism). The scientific method involves experimentation on the basis of hypotheses in order to answer questions and explore observations.

In framing a hypothesis, the investigator must not currently know the outcome of a test or that it remains reasonably under continuing investigation. Only in such cases does the experiment, test or study potentially increase the probability of showing the truth of a hypothesis. If the researcher already knows the outcome, it counts as a "consequence" — and the researcher should have already considered this while formulating the hypothesis. If one cannot assess the predictions by observation or by experience, the hypothesis classes as not yet useful, and must wait for others who might come afterward to make possible the needed observations. For example, a new technology or theory might make the necessary experiments feasible.

Scientific hypothesis

People refer to a trial solution to a problem as a hypothesis — often called an "educated guess"[5] — because it provides a suggested solution based on the evidence. Experimenters may test and reject several hypotheses before solving the problem.

According to Schick and Vaughn,[6] researchers weighing up alternative hypotheses may take into consideration:

- Testability (compare falsifiability as discussed above)
- Simplicity (as in the application of "Occam's razor", discouraging the postulation of excessive numbers of entities)
- Scope – the apparent application of the hypothesis to multiple cases of phenomena
- Fruitfulness – the prospect that a hypothesis may explain further phenomena in the future
- Conservatism – the degree of "fit" with existing recognized knowledge-systems

Evaluating hypotheses

Karl Popper's formulation of hypothetico-deductive method, which he called the method of "conjectures and refutations", demands falsifiable hypotheses, framed in such a manner that the scientific community can prove them false (usually by observation). According to this view, a hypothesis cannot be "confirmed", because there is always the possibility that a future experiment will show that it is false. Hence, failing to falsify a hypothesis does not prove that hypothesis: it remains provisional. However, a hypothesis that has been rigorously tested and not falsified can form a reasonable basis for action, i.e., we can act as if it were true, until such time as it is falsified. Just because we've never observed rain falling upward, doesn't mean that we never will—however improbable, our theory of gravity may be falsified some day.

Popper's view is not the only view on evaluating hypotheses. For example, some forms of empiricism hold that under a well-crafted, well-controlled experiment, a lack of falsification *does* count as verification, since such an experiment ranges over the full scope of possibilities in the problem domain. Should we ever discover some place where gravity did not function, and rain fell upward, this would not falsify our current theory of gravity (which, on this view, has been verified by innumerable well-formed experiments in the past) – it would rather suggest an expansion of our theory to encompass some new force or previously undiscovered interaction of forces. In other words, our initial theory as it stands is verified but incomplete. This situation illustrates the importance of having well-crafted, well-controlled experiments that range over the full scope of possibilities for applying the theory.

In recent years philosophers of science have tried to integrate the various approaches to evaluating hypotheses, and the scientific method in general, to form a more complete system that integrates the individual concerns of each approach. Notably, Imre Lakatos and Paul Feyerabend, both former students of Popper, have produced novel attempts at such a synthesis.

Hypotheses, Concepts and Measurement

Concepts, as abstract units of meaning, play a key role in the development and testing of hypotheses. Concepts are the basic components of hypotheses. Most formal hypotheses connect concepts by specifying the expected relationships between concepts. For example, a simple relational hypothesis such as “education increases income” specifies a positive relationship between the concepts “education” and “income.” This abstract or conceptual hypothesis cannot be tested. First, it must be operationalized or situated in the real world by rules of interpretation. Consider again the simple hypothesis “Education increases Income.” To test the hypothesis the abstract meaning of education and income must be derived or operationalized. The concepts should be measured. Education could be measured by “years of school completed” or “highest degree completed” etc. Income could be measured by “hourly rate of pay” or “yearly salary” etc.

When a set of hypotheses are grouped together they become a type of conceptual framework. When a conceptual framework is complex and incorporates causality or explanation it is generally referred to as a theory. According to noted philosopher of science Carl Gustav Hempel “An adequate empirical interpretation turns a theoretical system into a testable theory: The hypothesis whose constituent terms have been interpreted become capable of test by reference to observable phenomena. Frequently the interpreted hypothesis will be derivative hypotheses of the theory; but their confirmation or disconfirmation by empirical data will then immediately strengthen or weaken also the primitive hypotheses from which they were derived.”[7]

Hempel provides a useful metaphor that describes the relationship between a conceptual framework and the framework as it is observed and perhaps tested (interpreted framework). “The whole system floats, as it were, above the plane of observation and is anchored to it by rules of interpretation. These might be viewed as strings which are not part of the network but link certain points of the latter with specific places in the plane of observation. By virtue of those interpretative connections, the network can function as a scientific theory”[8] Hypotheses with concepts anchored in the plane of observation are ready to be tested. In “actual scientific practice the process of framing a theoretical structure and of interpreting it are not always sharply separated, since the intended interpretation usually guides the construction of the theoretician.”[9] It is, however, “possible and indeed desirable, for the purposes of logical clarification, to separate the two steps conceptually.”[9]

Statistical hypothesis testing

When a possible correlation or similar relation between phenomena is investigated, such as, for example, whether a proposed remedy is effective in treating a disease, that is, at least to some extent and for some patients, the hypothesis that a relation exists cannot be examined the same way one might examine a proposed new law of nature: in such an investigation a few cases in which the tested remedy shows no effect do not falsify the hypothesis. Instead, statistical tests are used to determine how likely it is that the overall effect would be observed if no real relation as hypothesized exists. If that likelihood is sufficiently small (e.g., less than 1%), the existence of a relation may be assumed. Otherwise, any observed effect may as well be due to pure chance.

In statistical hypothesis testing two hypotheses are compared, which are called the null hypothesis and the alternative hypothesis. The null hypothesis is the hypothesis that states that there is no relation between the phenomena whose relation is under investigation, or at least not of the form given by the alternative hypothesis. The alternative hypothesis, as the name suggests, is the alternative to the null hypothesis: it states that there *is* some kind of relation. The alternative hypothesis may take several forms, depending on the nature of the hypothesized relation; in particular, it can be two-sided (for example: there is *some* effect, in a yet unknown direction) or one-sided (the direction of the hypothesized relation, positive or negative, is fixed in advance).

Proper use of statistical testing requires that these hypotheses, and the threshold (such as 1%) at which the null hypothesis is rejected and the alternative hypothesis is accepted, all be determined in advance, before the observations are collected or inspected. If these criteria are determined later, when the data to be tested is already known, the test is invalid.

See also

- Case study
- Conceptual framework
- Confirmation holism
- Ecological fallacy
- Empiricism
- Hypothesis Theory, a research area in Cognitive Psychology
- Learning
- Logic
- Logical Positivism
- Operationalization
- *Philosophiae Naturalis Principia Mathematica* for Newton's position on hypotheses
- Reductionism
- Research design
- Scientific method
- Sociology of scientific knowledge
- Theory
- Thought experiment
- Working hypothesis

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[1] Wilbur R. Knorr, "Construction as existence proof in ancient geometry", p. 125, as selected by Jean Christianidis (ed.), *Classics in the history of Greek mathematics*, Kluwer.

[2] Gregory Vlastos, Myles Burnyeat (1994) *Socratic studies*, Cambridge ISBN 0521447356, p. 1

[3] "Neutral hypotheses, those of which the subject matter can never be directly proved or disproved, are very numerous in all sciences." — Morris Cohen and Ernest Nagel (1934) *An introduction to logic and scientific method* p. 375. New York: Harcourt, Brace, and Company.

[4] "Bellarmine (Ital. *Bellarmino*), Roberto Francesco Romolo", *Encyclopædia Britannica*, Eleventh Edition.: 'Bellarmine did not proscribe the Copernican system ... all he claimed was that it should be presented as an hypothesis until it should receive scientific demonstration.'

[5] "When it is not clear under which law of nature an effect or class of effect belongs, we try to fill this gap by means of a guess. Such guesses have been given the name *conjectures* or *hypotheses*." — Hans Christian Ørsted(1811) "First Introduction to General Physics" ¶18. *Selected Scientific Works of Hans Christian Ørsted*, ISBN 0-691-04334-5 p.297

[6] Schick, Theodore; Vaughn, Lewis (2002). *How to think about weird things: critical thinking for a New Age*. Boston: McGraw-Hill Higher Education. ISBN 0-7674-2048-9.

[7] Hempel, C. G. (1952). Fundamentals of concept formation in empirical science. Chicago, IL: The University of Chicago Press, p. 36

[8] Hempel, C. G. (1952). Fundamentals of concept formation in empirical science. Chicago, IL: The University of Chicago Press, p. 36.

[9] Hempel, C. G. (1952). Fundamentals of concept formation in empirical science. Chicago, IL: The University of Chicago Press, p. 33.

Imagination

Imagination, also called the faculty of **imagining**, is the ability of forming mental images, sensations and concepts, in a moment when they are not perceived through sight, hearing or other senses. Imagination is the work of the mind that helps create. Imagination helps provide meaning to experience and understanding to knowledge; it is a fundamental facility through which people make sense of the world,[1] [2] [3] and it also plays a key role in the learning process.[1] [4] A basic training for imagination is listening to storytelling (narrative),[1] [5] in which the exactness of the chosen words is the fundamental factor to "evoke worlds."[6]

Olin Levi Warner, *Imagination* (1896). Library of Congress Thomas Jefferson Building, Washington, D.C.

Imagination is the faculty through which we encounter everything. The things that we touch, see and hear coalesce into a "picture" via our imagination.

It is accepted as the innate ability and process of inventing partial or complete personal realms within the mind from elements derived from sense perceptions of the shared world. The term is technically used in psychology for the process of reviving in the mind, percepts of objects formerly given in sense perception. Since this use of the term conflicts with that of ordinary language, some psychologists have preferred to describe this process as "imaging" or "imagery" or to speak of it as "reproductive" as opposed to "productive" or "constructive" imagination. Imagined images are seen with the "mind's eye."

Imagination can also be expressed through stories such as fairy tales or fantasies. Most famous inventions or entertainment products were created from the inspiration of someone's imagination.

Children often use narratives or pretend play in order to exercise their imagination. When children create fantasy they play at two levels: first, they use role playing to act out what they have created with their imagination, and at the second level they play again with their make-believe situation by acting as if what they have created is an actual reality that already exists in narrative myth.[7]

Description

The common use of the term is for the process of forming new images in the mind that have not been previously experienced, or at least only partially or in different combinations. Some typical examples follow:

- Fairy tale
- Fiction
- A form of verisimilitude often invoked in fantasy and science fiction invites readers to pretend such stories are true by referring to objects of the mind such as fictional books or years that do not exist apart from an imaginary world.

Imagination in this sense, not being limited to the acquisition of exact knowledge by the requirements of practical necessity, is, up to a certain point, free from objective restraints. The ability to imagine one's self in another person's place is very important to social relations and understanding. Albert Einstein said, "Imagination ... is more important than knowledge. Knowledge is limited. Imagination encircles the world."[8]

In various spheres, however, even imagination is in practice limited: thus a person whose imaginations do violence to the elementary laws of thought, or to the necessary principles of practical possibility, or to the reasonable probabilities of a given case is regarded as insane.

The same limitations beset imagination in the field of scientific hypothesis. Progress in scientific research is due largely to provisional explanations which are constructed by imagination, but such hypotheses must be framed in relation to previously ascertained facts and in accordance with the principles of the particular science.

Imagination is an experimental partition of the mind used to create theories and ideas based on functions. Taking objects from real perceptions, the imagination uses complex IF-functions to create new or revised ideas. This part of the mind is vital to developing better and easier ways to accomplish old and new tasks. These experimental ideas can be safely conducted inside a virtual world and then, if the idea is probable and the function is true, the idea can be actualized in reality. Imagination is the key to new development of the mind and can be shared with others, progressing collectively.

Regarding the volunteer effort, imagination can be classified as:

- voluntary (the dream from the sleep, the daydream)
- involuntary (the reproductive imagination, the creative imagination, the dream of perspective)

Psychology of imagination

Psychologists have studied imaginative thought, not only in its exotic form of creativity and artistic expression but also in its mundane form of everyday imagination.[9] Ruth M.J. Byrne has proposed that everyday imaginative thoughts about counterfactual alternatives to reality may be based on the same cognitive processes that rational thoughts are based on.[10] Children can engage in the creation of imaginative alternatives to reality from their very early years.[11]

Imagination and perception

From the work of Piaget it is known that perceptions depend on the world view of a person. The world view is the result of arranging perceptions into existing imagery by imagination. Piaget cites the example of a child saying that the moon is following her when she walks around the village at night. Like this perceptions are integrated into the world view to make sense. Imagination is needed to make sense of perceptions.[12]

Imagination vs. belief

Imagination differs fundamentally from belief because the subject understands that what is personally invented by the mind does not necessarily impact the course of action taken in the apparently shared world while beliefs are part of what one holds as truths about both the shared and personal worlds. The play of imagination, apart from the obvious limitations (e.g. of avoiding explicit self-contradiction), is conditioned only by the general trend of the mind at a given moment. Belief, on the other hand, is immediately related to practical activity: it is perfectly possible to imagine oneself a millionaire, but unless one believes it one does not, therefore, act as such. Belief endeavors to conform to the subject's experienced conditions or faith in the possibility of those conditions; whereas imagination as such is specifically free. The dividing line between imagination and belief varies widely in different stages of technological development. Thus in more extreme cases, someone from a primitive culture who ill frames an ideal reconstruction of the causes of his illness, and attributes it to the hostile magic of an enemy based on faith and tradition rather than science. In ignorance of the science of pathology the subject is satisfied with this explanation, and actually believes in it, sometimes to the point of death, due to what is known as the nocebo effect.

It follows that the learned distinction between imagination and belief depends in practice on religion, tradition, and culture.

Imagination as a reality

The world as experienced is an interpretation of data arriving from the senses, as such it is perceived as real by contrast to most thoughts and imaginings. Users of hallucinogenic drugs are said to have a heightened imagination. This difference is only one of degree and can be altered by several historic causes, namely changes to brain chemistry, hypnosis or other altered states of consciousness, meditation, many hallucinogenic drugs, and electricity applied directly to specific parts of the brain. The difference between imagined and perceived reality can be proven by psychosis. Many mental illnesses can be attributed to this inability to distinguish between the sensed and the internally created worlds. Some cultures and traditions even view the apparently shared world as an illusion of the mind as with the Buddhist maya or go to the opposite extreme and accept the imagined and dreamed realms as of equal validity to the apparently shared world as the Australian Aborigines do with their concept of dreamtime.

Imagination, because of having freedom from external limitations, can often become a source of real pleasure and unnecessary suffering. Consistent with this idea, imagining pleasurable and fearful events is found to engage emotional circuits involved in emotional perception and experience.[13] A person of vivid imagination often suffers acutely from the imagined perils besetting friends, relatives, or even strangers such as celebrities. Also crippling fear can result from taking an imagined painful future too seriously.

Imagination can also produce some symptoms of real illnesses. In some cases, they can seem so "real" that specific physical manifestations occur such as rashes and bruises appearing on the skin, as though imagination had passed into belief or the events imagined were actually in progress. See, for example, psychosomatic illness and folie a deux.

It has also been proposed that the whole of human cognition is based upon imagination. That is, nothing that is perceived is purely observation but all is a morph between sense and imagination.

Imagination preceding reality

When two existing perceptions (thesis and antithesis) are combined within the mind, a third perception (called synthesis) is formed. At this point, perception only exists as part of the imagination and can become the inspiration for a new invention or technique.

See also

- Art
- Creativity
- Idea
- Fantasy

Notes

[1] Norman 2000 pp. 1-2
[2] Brian Sutton-Smith 1988, p. 22
[3] Archibald MacLeish 1970, p. 887
[4] Kieran Egan 1992, pp. 50
[5] Northrop Frye 1963, p. 49
[6] As noted by Giovanni Pascoli
[7] Laurence Goldman (1998). *Child's play: myth, mimesis and make-believe. Basically what this means is that the children use their make-believe situation and act as if what they are acting out is from a reality that already exists even though they have made it up.*. Berg Publishers. ISBN 1-85973-918-0.
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[13] Costa, VD, Lang, PJ, Sabatinelli, D, Bradley MM, and Versace, F (2010). "Emotional imagery: Assessing pleasure and arousal in the brain's reward circuitry". *Human Brain Mapping* **31** (9): 1446–1457. doi:10.1002/hbm.20948. PMID 20127869.

External links

- Imagination, Mental Imagery, Consciousness, and Cognition: Scientific, Philosophical and Historical Approaches (http://www.imagery-imagination.com/)
- Two-Factor Imagination Scale (http://search.dmoz.org/cgi-bin/search?search=Two-Factor+Imagination+Scale&all=yes&cs=UTF-8&cat=Science/Social_Sciences/Psychology/Intelligence/Emotional_Intelligence/Online_Tests) at the Open Directory Project

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See also:

- Alice in wonderland
- Watkins, Mary: "Waking Dreams" [Harper Colophon Books, 1976] and "Invisible Guests - The Development of Imaginal Dialogues" [The Analytic Press, 1986]
- Moss, Robert: "The Three "Only" Things: Tapping the Power of Dreams, Coincidence, and Imagination" [New World Library, September 10, 2007]

Two philosophers for whom imagination is a central concept are John Sallis and Richard Kearney. See in particular:

- John Sallis, *Force of Imagination: The Sense of the Elemental* (2000)
- John Sallis, *Spacings-Of Reason and Imagination. In Texts of Kant, Fichte, Hegel* (1987)
- Richard Kearney, *The Wake of Imagination.* Minneapolis: University of Minnesota Press (1988); 1st Paperback Edition- (ISBN 0-8166-1714-7)
- Richard Kearney, "Poetics of Imagining: Modern to Post-modern." Fordham University Press (1998)

See also

Inductive reasoning

Inductive reasoning, also known as **induction** or **inductive logic**, or **educated guess** in colloquial English, is a kind of reasoning that draws generalized conclusions from a finite collection of specific observations. The premises of an inductive logical argument indicate some degree of support (inductive probability) for the conclusion but do not entail it; that is, they suggest truth but do not ensure it.

Induction is employed, for example, in the following argument:

> All of the ice we have examined so far is cold. (Specific observations)
>
> Therefore, all ice is cold. (Generalized conclusion)

or,

> The person looks uncomfortable
>
> Therefore, the person is always uncomfortable.

Inductive reasoning allows for the possibility that the conclusion is false, even where all of the premises are true.[1] For example:

> All of the swans we have seen are white.
>
> All swans are white. (Only if we disregard Black Swans)

Note that this definition of *inductive* reasoning excludes mathematical induction, which is considered to be a form of *deductive* reasoning.

Strong and weak induction

The words 'strong' and 'weak' are sometimes used to praise or demean the goodness of an inductive argument. The idea is that you say "this is an example of strong induction" when you would decide to believe the conclusion if presented with the premises. Alternatively, you say "that is weak induction" when your particular world view does not allow you to see that the conclusions are likely given the premises.

Strong induction

> The equation, "the gravitational force between two objects equals the gravitational constant times the product of the masses divided by the distance between them squared," has allowed us to describe the rate of fall of all objects we have observed.
>
> Therefore:
>
> The gravitational force between two objects equals the gravitational constant times the product of the masses divided by the distance between them squared.

The conclusion of this argument is not absolutely certain, even given the premise. At speeds we normally experience, Newtonian mechanics holds quite well. But at speeds approaching that of light, the Newtonian system is not accurate and the conclusion in that case would be false. However, since, in most cases that we experience, the premise as stated would usually lead to the conclusion given, we are logical in calling this argument an instance of strong induction.

Weak induction

Consider this example:

I always hang pictures on nails.

Therefore:

All pictures hang from nails.

Here, the link between the premise and the conclusion is very weak. Not only is it possible for the conclusion to be false given the premise, it is even fairly likely that the conclusion is false. Not all pictures are hung from nails; moreover, not all pictures are hung. Thus we say that this argument is an instance of weak induction.

Is induction reliable?

Inductive reasoning has been attacked for millennia by thinkers as diverse as Sextus Empiricus[2] and Karl Popper.[3]

The classic philosophical treatment of the problem of induction was given by the Scottish philosopher David Hume. Hume highlighted the fact that our everyday functioning depends on drawing uncertain conclusions from our relatively limited experiences rather than on deductively valid arguments. For example, we believe that bread will nourish us because it has done so in the past, despite no guarantee that it will do so. However, Hume argued that it is impossible to justify inductive reasoning. Inductive reasoning certainly cannot be justified deductively, and so our only option is to justify it inductively. However, to justify induction inductively is circular. Therefore, it is impossible to justify induction.[4]

However, Hume immediately argued that even if induction were proved unreliable, we would have to rely on it. So he took a middle road. Rather than approach everything with severe skepticism, Hume advocated a practical skepticism based on common sense, where the inevitability of induction is accepted.[5]

Types of inductive reasoning

Generalization

A generalization (more accurately, an *inductive generalization*) proceeds from a premise about a sample to a conclusion about the population.

The proportion Q of the sample has attribute A.

Therefore:

The proportion Q of the population has attribute A.

Example

There are 20 balls in an urn, either black or white. To estimate their respective numbers you draw a sample of 4 balls and find that 3 are black, one is white. A good inductive generalisation would be: there are 15 black and 5 white balls in the urn.

How great the support is which the premises provide for the conclusion is dependent on (a) the number of individuals in the sample group compared to the number in the population; and (b) the degree to which the sample is representative of the population (which may be achieved by taking a random sample). The hasty generalization and biased sample are fallacies related to generalisation.

Statistical syllogism

A statistical syllogism proceeds from a generalization to a conclusion about an individual.

> A proportion Q of population P has attribute A.
>
> An individual X is a member of P.
>
> Therefore:
>
> There is a probability which corresponds to Q that X has A.

The proportion in the first premise would be something like "3/5ths of", "all", "few", etc. Two dicto simpliciter fallacies can occur in statistical syllogisms: "accident" and "converse accident".

Simple induction

Simple induction proceeds from a premise about a sample group to a conclusion about another individual.

> Proportion Q of the known instances of population P has attribute A.
>
> Individual I is another member of P.
>
> Therefore:
>
> There is a probability corresponding to Q that I has A.

This is a combination of a generalization and a statistical syllogism, where the conclusion of the generalization is also the first premise of the statistical syllogism.

Argument from analogy

Some philosophers believe that an argument from analogy is a kind of inductive reasoning.

An argument from analogy has the following form:

> I has attributes A, B, and C
>
> J has attributes A and B
>
> So, J has attribute C

An analogy relies on the inference that the attributes known to be shared (the similarities) imply that C is also a shared property. The support which the premises provide for the conclusion is dependent upon the relevance and number of the similarities between I and J. The fallacy related to this process is false analogy. As with other forms of inductive argument, even the best reasoning in an argument from analogy can only make the conclusion probable given the truth of the premises, not certain.

Analogical reasoning is very frequent in common sense, science, philosophy and the humanities, but sometimes it is accepted only as an auxiliary method. A refined approach is case-based reasoning. For more information on inferences by analogy, see Juthe, 2005 [6].

Causal inference

A causal inference draws a conclusion about a causal connection based on the conditions of the occurrence of an effect. Premises about the correlation of two things can indicate a causal relationship between them, but additional factors must be confirmed to establish the exact form of the causal relationship.

Prediction

A prediction draws a conclusion about a future individual from a past sample.

> Proportion Q of observed members of group G have had attribute A.
>
> Therefore:
>
> There is a probability corresponding to Q that other members of group G will have attribute A when next observed.

Bayesian inference

Of the candidate systems for an inductive logic, the most influential is Bayesianism. As a logic of induction rather than a theory of belief, Bayesianism does not determine which beliefs are *a priori* rational, but rather determines how we should rationally change the beliefs we have when presented with evidence. We begin by committing to a (really any) hypothesis, and when faced with evidence, we adjust the strength of our belief in that hypothesis in a precise manner using Bayesian logic.

See also

- Abductive reasoning
- Analogy
- Deductive reasoning
- Explanation
- Falsifiability
- Inductive reasoning aptitude
- Inductive Logic Programming
- Inferential statistics
- Inquiry
- Logic
- Machine learning
- Mathematical induction
- Mill's Methods
- Raven paradox
- Retroduction
- Laurence Jonathan Cohen
- Counterinduction

Footnotes

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[5] Vickers, John. "The Problem of Induction" (http://plato.stanford.edu/entries/induction-problem/#IndJus) (Section 2.1). *Stanford Encyclopedia of Philosophy*. 21 June 2010.
[6] http://www.cs.hut.fi/Opinnot/T-93.850/2005/Papers/juthe2005-analogy.pdf

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External links

- *Four Varieties of Inductive Argument* (http://www.uncg.edu/phi/phi115/induc4.htm) from the Department of Philosophy, University of North Carolina at Greensboro.
- *Inductive Logic* (http://plato.stanford.edu/entries/logic-inductive/) from the Stanford Encyclopedia of Philosophy.
- *Properties of Inductive Reasoning* (http://faculty.ucmerced.edu/eheit/heit2000.pdf)PDF (166 KiB), a psychological review by Evan Heit of the University of California, Merced.
- *The Mind, Limber* (http://dudespaper.com/the-mind-limber.html) An article which employs the film The Big Lebowski to explain the value of inductive reasoning.

Inference

Inference is a good guess heuristics (based on logic, statistics etc.) to observations or by interpolating the next logical step in an intuited pattern. The conclusion drawn is also called an inference. The laws of valid inference are studied in the field of logic.

Human inference (i.e. how humans draw conclusions) is traditionally studied within the field of cognitive psychology; artificial intelligence researchers develop automated inference systems to emulate human inference. Statistical inference allows for inference from quantitative data.

Accuracy of inductive inferences

The process by which a conclusion is inferred from multiple observations is called inductive reasoning. The conclusion may be correct or incorrect, or correct to within a certain degree of accuracy, or correct in certain situations. Conclusions inferred from multiple observations may be tested by additional observations.

Examples of deductive inference

Greek philosophers defined a number of syllogisms, correct three part inferences, that can be used as building blocks for more complex reasoning. We begin with the most famous of them all:

1. All men are mortal
2. Socrates is a man
3. Therefore, Socrates is mortal.

The reader can check that the premises and conclusion are true, but Logic is concerned with inference: does the truth of the conclusion follow from that of the premises?

The validity of an inference depends on the form of the inference. That is, the word "valid" does not refer to the truth of the premises or the conclusion, but rather to the form of the inference. An inference can be valid even if the parts are false, and can be invalid even if the parts are true. But a valid form with true premises will always have a true conclusion.

For example, consider the form of the following symbological track:

1. All apples are blue.
2. A banana is an apple.
3. Therefore, a banana is blue.

For the conclusion to be necessarily true, the premises need to be true.

Now we turn to an invalid form.

1. All A are B.
2. C is a B.
3. Therefore, C is an A.

To show that this form is invalid, we demonstrate how it can lead from true premises to a false conclusion.

1. All apples are fruit. (True)
2. Bananas are fruit. (True)
3. Therefore, bananas are apples. (False)

A valid argument with false premises may lead to a false conclusion:

1. All fat people are Greek.
2. John Lennon was fat.
3. Therefore, John Lennon was Greek.

When a valid argument is used to derive a false conclusion from false premises, the inference is valid because it follows the form of a correct inference.

A valid argument can also be used to derive a true conclusion from false premises:

1. All fat people are musicians
2. John Lennon was fat
3. Therefore, John Lennon was a musician

In this case we have two false premises that imply a true conclusion.

Incorrect inference

An incorrect inference is known as a fallacy. Philosophers who study informal logic have compiled large lists of them, and cognitive psychologists have documented many biases in human reasoning that favor incorrect reasoning.

Automatic logical inference

AI systems first provided automated logical inference and these were once extremely popular research topics, leading to industrial applications under the form of expert systems and later business rule engines.

An inference system's job is to extend a knowledge base automatically. The knowledge base (KB) is a set of propositions that represent what the system knows about the world. Several techniques can be used by that system to extend KB by means of valid inferences. An additional requirement is that the conclusions the system arrives at are relevant to its task.

Example using Prolog

Prolog (for "Programming in Logic") is a programming language based on a subset of predicate calculus. Its main job is to check whether a certain proposition can be inferred from a KB (knowledge base) using an algorithm called backward chaining.

Let us return to our Socrates syllogism. We enter into our Knowledge Base the following piece of code:

```
mortal(X) :-        man(X).
man(socrates).
```

(Here ***:-*** can be read as if. Generally, if $P \longrightarrow Q$ (if P then Q) then in Prolog we would code ***Q:-P*** (Q if P).)
This states that all men are mortal and that Socrates is a man. Now we can ask the Prolog system about Socrates:

```
?- mortal(socrates).
```

(where *?-* signifies a query: Can *mortal(socrates).* be deduced from the KB using the rules) gives the answer "Yes".

On the other hand, asking the Prolog system the following:

```
?- mortal(plato).
```

gives the answer "No".

This is because Prolog does not know anything about Plato, and hence defaults to any property about Plato being false (the so-called closed world assumption). Finally ?- mortal(X) (Is anything mortal) would result in "Yes" (and in some implemenations: "Yes": X=socrates)
Prolog can be used for vastly more complicated inference tasks. See the corresponding article for further examples.

Use with the semantic web

Recently automatic reasoners found in semantic web a new field of application. Being based upon first-order logic, knowledge expressed using one variant of OWL can be logically processed, i.e., inferences can be made upon it.

Bayesian statistics and probability logic

Philosophers and scientists who follow the Bayesian framework for inference use the mathematical rules of probability to find this best explanation. The Bayesian view has a number of desirable features—one of them is that it embeds deductive (certain) logic as a subset (this prompts some writers to call Bayesian probability "probability logic", following E. T. Jaynes).

Bayesians identify probabilities with degrees of beliefs, with certainly true propositions having probability 1, and certainly false propositions having probability 0. To say that "it's going to rain tomorrow" has a 0.9 probability is to say that you consider the possibility of rain tomorrow as extremely likely.

Through the rules of probability, the probability of a conclusion and of alternatives can be calculated. The best explanation is most often identified with the most probable (see Bayesian decision theory). A central rule of Bayesian inference is Bayes' theorem, which gave its name to the field.

See Bayesian inference for examples.

Nonmonotonic logic[1]

A relation of inference is monotonic if the addition of premises does not undermine previously reached conclusions; otherwise the relation is nonmonotonic. Deductive inference, at least according to the canons of classical logic, is monotonic: if a conclusion is reached on the basis of a certain set of premises, then that conclusion still holds if more premises are added.

By contrast, everyday reasoning is mostly nonmonotonic because it involves risk: we jump to conclusions from deductively insufficient premises. We know when it is worth or even necessary (e.g. in medical diagnosis) to take the risk. Yet we are also aware that such inference is defeasible—that new information may undermine old conclusions. Various kinds of defeasible but remarkably successful inference have traditionally captured the attention of philosophers (theories of induction, Peirce’s theory of abduction, inference to the best explanation, etc.). More recently logicians have begun to approach the phenomenon from a formal point of view. The result is a large body of theories at the interface of philosophy, logic and artificial intelligence.

See also

- Reasoning
  - Abductive reasoning
  - Deductive reasoning
  - Inductive reasoning
  - Retroductive reasoning
- Analogy
- Axiom
- Bayesian inference
- Business rule
- Business rules engine
- Expert system
- Fuzzy logic
- Immediate inference
- Inference engine
- Inquiry
- Logic
- Logic of information
- Logical assertion
- Logical graph
- Nonmonotonic logic
- Rule of inference
- List of rules of inference

- Theorem
- Sherlock Holmes

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Inquiry

An **inquiry** is any process that has the aim of augmenting knowledge, resolving doubt, or solving a problem. A theory of inquiry is an account of the various types of inquiry and a treatment of the ways that each type of inquiry achieves its aim.

Classical sources

Deduction

> When three terms are so related to one another that the last is wholly contained in the middle and the middle is wholly contained in or excluded from the first, the extremes must admit of perfect syllogism. By 'middle term' I mean that which both is contained in another and contains another in itself, and which is the middle by its position also; and by 'extremes' (a) that which is contained in another, and (b) that in which another is contained. For if *A* is predicated of all *B*, and *B* of all *C*, *A* must necessarily be predicated of all *C*. ... I call this kind of figure the First. (Aristotle, *Prior Analytics*, 1.4)

Induction

> Inductive reasoning consists in establishing a relation between one extreme term and the middle term by means of the other extreme; for example, if *B* is the middle term of *A* and *C*, in proving by means of *C* that *A* applies to *B*; for this is how we effect inductions. (Aristotle, *Prior Analytics*, 2.23)

Abduction

The *locus classicus* for the study of abductive reasoning is found in Aristotle's *Prior Analytics*, Book 2, Chapt. 25. It begins this way:

> We have Reduction (απαγωγη, abduction):
>
> 1. When it is obvious that the first term applies to the middle, but that the middle applies to the last term is not obvious, yet is nevertheless more probable or not less probable than the conclusion;
> 2. Or if there are not many intermediate terms between the last and the middle;
>
> For in all such cases the effect is to bring us nearer to knowledge.

By way of explanation, Aristotle supplies two very instructive examples, one for each of the two varieties of abductive inference steps that he has just described in the abstract:

1. For example, let *A* stand for "that which can be taught", *B* for "knowledge", and *C* for "morality". Then that knowledge can be taught is evident; but whether virtue is knowledge is not clear. Then if *BC* is not less probable or is more probable than *AC*, we have reduction; for we are nearer to knowledge for having introduced an additional term, whereas before we had no knowledge that *AC* is true.
2. Or again we have reduction if there are not many intermediate terms between *B* and *C*; for in this case too we are brought nearer to knowledge. For example, suppose that *D* is "to square", *E* "rectilinear figure", and *F* "circle". Assuming that between *E* and *F* there is only one intermediate term — that the circle becomes equal to a rectilinear figure by means of lunules — we should approximate to knowledge. (Aristotle, "Prior Analytics", 2.25, with minor alterations)

Aristotle's latter variety of abductive reasoning, though it will take some explaining in the sequel, is well worth our contemplation, since it hints already at streams of inquiry that course well beyond the syllogistic source from which they spring, and into regions that Peirce will explore more broadly and deeply.

Inquiry in the pragmatic paradigm

In the pragmatic philosophies of Charles Sanders Peirce, William James, John Dewey, and others, inquiry is closely associated with the normative science of logic. In its inception, the pragmatic model or theory of inquiry was extracted by Peirce from its raw materials in classical logic, with a little bit of help from Kant, and refined in parallel with the early development of symbolic logic by Boole, De Morgan, and Peirce himself to address problems about the nature and conduct of scientific reasoning. Borrowing a brace of concepts from Aristotle, Peirce examined three fundamental modes of reasoning that play a role in inquiry, commonly known as abductive, deductive, and inductive inference.

In rough terms, *abduction* is what we use to generate a likely hypothesis or an initial diagnosis in response to a phenomenon of interest or a problem of concern, while *deduction* is used to clarify, to derive, and to explicate the relevant consequences of the selected hypothesis, and *induction* is used to test the sum of the predictions against the sum of the data. It needs to be observed that the classical and pragmatic treatments of the types of reasoning, dividing the generic territory of inference as they do into three special parts, arrive at a different characterization of the environs of reason than do those accounts that count only two.

These three processes typically operate in a cyclic fashion, systematically operating to reduce the uncertainties and the difficulties that initiated the inquiry in question, and in this way, to the extent that inquiry is successful, leading to an increase in knowledge or in skills.

In the pragmatic way of thinking everything has a purpose, and the purpose of each thing is the first thing we should try to note about it. The purpose of inquiry is to reduce doubt and lead to a state of belief, which a person in that state will usually call *knowledge* or *certainty*. As they contribute to the end of inquiry, we should appreciate that the three kinds of inference describe a cycle that can be understood only as a whole, and none of the three makes complete sense in isolation from the others. For instance, the purpose of abduction is to generate guesses of a kind that deduction can explicate and that induction can evaluate. This places a mild but meaningful constraint on the production of hypotheses, since it is not just any wild guess at explanation that submits itself to reason and bows out when defeated in a match with reality. In a similar fashion, each of the other types of inference realizes its purpose only in accord with its proper role in the whole cycle of inquiry. No matter how much it may be necessary to study these processes in abstraction from each other, the integrity of inquiry places strong limitations on the effective modularity of its principal components.

Art and science of inquiry

For our present purposes, the first feature to note in distinguishing the three principal modes of reasoning from each other is whether each of them is exact or approximate in character. In this light, deduction is the only one of the three types of reasoning that can be made exact, in essence, always deriving true conclusions from true premises, while abduction and induction are unavoidably approximate in their modes of operation, involving elements of fallible judgment in practice and inescapable error in their application.

The reason for this is that deduction, in the ideal limit, can be rendered a purely internal process of the reasoning agent, while the other two modes of reasoning essentially demand a constant interaction with the outside world, a source of phenomena and problems that will no doubt continue to exceed the capacities of any finite resource, human or machine, to master. Situated in this larger reality, approximations can be judged appropriate only in relation to their context of use and can be judged fitting only with regard to a purpose in view.

A parallel distinction that is often made in this connection is to call deduction a *demonstrative* form of inference, while abduction and induction are classed as *non-demonstrative* forms of reasoning. Strictly speaking, the latter two modes of reasoning are not properly called inferences at all. They are more like controlled associations of words or ideas that just happen to be successful often enough to be preserved as useful heuristic strategies in the repertoire of the agent. But non-demonstrative ways of thinking are inherently subject to error, and must be constantly checked out and corrected as needed in practice.

In classical terminology, forms of judgment that require attention to the context and the purpose of the judgment are said to involve an element of "art", in a sense that is judged to distinguish them from "science", and in their renderings as expressive judgments to implicate arbiters in styles of rhetoric, as contrasted with logic.

In a figurative sense, this means that only deductive logic can be reduced to an exact theoretical science, while the practice of any empirical science will always remain to some degree an art.

Zeroth order inquiry

Many aspects of inquiry can be recognized and usefully studied in very basic logical settings, even simpler than the level of syllogism, for example, in the realm of reasoning that is variously known as *Boolean algebra*, *propositional calculus*, *sentential calculus*, or *zeroth-order logic*. By way of approaching the learning curve on the gentlest availing slope, we may well begin at the level of *zeroth-order inquiry*, in effect, taking the syllogistic approach to inquiry only so far as the propositional or sentential aspects of the associated reasoning processes are concerned. One of the bonuses of doing this in the context of Peirce's logical work is that it provides us with doubly instructive exercises in the use of his logical graphs, taken at the level of his so-called "alpha graphs".

In the case of propositional calculus or sentential logic, deduction comes down to applications of the transitive law for conditional implications and the approximate forms of inference hang on the properties that derive from these. In describing the various types of inference I will employ a few old "terms of art" from classical logic that are still of use in treating these kinds of simple problems in reasoning.

Deduction takes a Case, the minor premise $X \Rightarrow Y$
and combines it with a Rule, the major premise $Y \Rightarrow Z$
to arrive at a Fact, the demonstrative conclusion $X \Rightarrow Z.$

Induction takes a Case of the form $X \Rightarrow Y$
and matches it with a Fact of the form $X \Rightarrow Z$
to infer a Rule of the form $Y \Rightarrow Z.$

Abduction takes a Fact of the form $X \Rightarrow Z$
and matches it with a Rule of the form $Y \Rightarrow Z$
to infer a Case of the form $X \Rightarrow Y.$

For ease of reference, Figure 1 and the Legend beneath it summarize the classical terminology for the three types of inference and the relationships among them.

```
o-------------------------------------------------o
|                                                 |
|                   Z                             |
|                   o                             |
|                   |\                            |
|                   | \                           |
|                   |  \                          |
|                   |   \                         |
|                   |    \                        |
|                   |     \   R U L E             |
|                   |      \                      |
|                   |       \                     |
|               F   |        \                    |
|                   |         \                   |
|               A   |          \                  |
|                   |           o Y               |
|               C   |          /                  |
|                   |         /                   |
|               T   |        /                    |
|                   |       /                     |
|                   |      /                      |
|                   |     /   C A S E             |
|                   |    /                        |
|                   |   /                         |
|                   |  /                          |
|                   | /                           |
|                   |/                            |
|                   o                             |
|                   X                             |
|                                                 |
| Deduction takes a Case of the form X →Y,        |
| matches it with a Rule of the form Y →Z,        |
| then adverts to a Fact of the form X →Z.        |
|                                                 |
| Induction takes a Case of the form X →Y,        |
| matches it with a Fact of the form X →Z,        |
| then adverts to a Rule of the form Y →Z.        |
|                                                 |
| Abduction takes a Fact of the form X →Z,        |
| matches it with a Rule of the form Y →Z,        |
| then adverts to a Case of the form X →Y.        |
|                                                 |
| Even more succinctly:                           |
|                                                 |
|           Abduction  Deduction  Induction       |
```

```
|                                                 |
| Premise:     Fact        Case        Case       |
| Premise:     Rule        Rule        Fact       |
| Outcome:     Case        Fact        Rule       |
|                                                 |
o-------------------------------------------------o
Figure 1.  Elementary Structure and Terminology
```

In its original usage a statement of Fact has to do with a deed done or a record made, that is, a type of event that is openly observable and not riddled with speculation as to its very occurrence. In contrast, a statement of Case may refer to a hidden or a hypothetical cause, that is, a type of event that is not immediately observable to all concerned. Obviously, the distinction is a rough one and the question of which mode applies can depend on the points of view that different observers adopt over time. Finally, a statement of a Rule is called that because it states a regularity or a regulation that governs a whole class of situations, and not because of its syntactic form. So far in this discussion, all three types of constraint are expressed in the form of conditional propositions, but this is not a fixed requirement. In practice, these modes of statement are distinguished by the roles that they play within an argument, not by their style of expression. When the time comes to branch out from the syllogistic framework, we will find that propositional constraints can be discovered and represented in arbitrary syntactic forms.

Usman and Kishore

Example of inquiry

Examples of inquiry, that illustrate the full cycle of its abductive, deductive, and inductive phases, and yet are both concrete and simple enough to be suitable for a first (or zeroth) exposition, are somewhat rare in Peirce's writings, and so let us draw one from the work of fellow pragmatician John Dewey, analyzing it according to the model of zeroth-order inquiry that we developed above.

> A man is walking on a warm day. The sky was clear the last time he observed it; but presently he notes, while occupied primarily with other things, that the air is cooler. It occurs to him that it is probably going to rain; looking up, he sees a dark cloud between him and the sun, and he then quickens his steps. What, if anything, in such a situation can be called thought? Neither the act of walking nor the noting of the cold is a thought. Walking is one direction of activity; looking and noting are other modes of activity. The likelihood that it will rain is, however, something *suggested*. The pedestrian *feels* the cold; he *thinks of* clouds and a coming shower. (John Dewey, *How We Think*, pp. 6-7).

Once over quickly

Let's first give Dewey's elegant example of inquiry in everyday life the quick once over, hitting just the high points of its analysis into Peirce's three kinds of reasoning.

Abductive phase

In Dewey's "Rainy Day" or "Sign of Rain" story, we find our peripatetic hero presented with a surprising Fact:

- Fact: $C \to A$, In the Current situation the Air is cool.

Responding to an intellectual reflex of puzzlement about the situation, his resource of common knowledge about the world is impelled to seize on an approximate Rule:

- Rule: $B \to A$, Just Before it rains, the Air is cool.

This Rule can be recognized as having a potential relevance to the situation because it matches the surprising Fact, $C \to A$, in its consequential feature A.

All of this suggests that the present Case may be one in which it is just about to rain:

- Case: C → B, The Current situation is just Before it rains.

The whole mental performance, however automatic and semi-conscious it may be, that leads up from a problematic Fact and a previously settled knowledge base of Rules to the plausible suggestion of a Case description, is what we are calling an abductive inference.

Deductive phase

The next phase of inquiry uses deductive inference to expand the implied consequences of the abductive hypothesis, with the aim of testing its truth. For this purpose, the inquirer needs to think of other things that would follow from the consequence of his precipitate explanation. Thus, he now reflects on the Case just assumed:

- Case: C → B, The Current situation is just Before it rains.

He looks up to scan the sky, perhaps in a random search for further information, but since the sky is a logical place to look for details of an imminent rainstorm, symbolized in our story by the letter B, we may safely suppose that our reasoner has already detached the consequence of the abduced Case, C → B, and has begun to expand on its further implications. So let us imagine that our up-looker has a more deliberate purpose in mind, and that his search for additional data is driven by the new-found, determinate Rule:

- Rule: B → D, Just Before it rains, Dark clouds appear.

Contemplating the assumed Case in combination with this new Rule leads him by an immediate deduction to predict an additional Fact:

- Fact: C → D, In the Current situation Dark clouds appear.

The reconstructed picture of reasoning assembled in this second phase of inquiry is true to the pattern of deductive inference.

Inductive phase

Whatever the case, our subject observes a Dark cloud, just as he would expect on the basis of the new hypothesis. The explanation of imminent rain removes the discrepancy between observations and expectations and thereby reduces the shock of surprise that made this process of inquiry necessary.

Looking more closely

Seeding hypotheses

Figure 4 gives a graphical illustration of Dewey's example of inquiry, isolating for the purposes of the present analysis the first two steps in the more extended proceedings that go to make up the whole inquiry.

```
o-----------------------------------------------------------o
|                                                           |
|     A                                               D     |
|      o                                             o      |
|       \ *                                       * /       |
|        \  *                                   *  /        |
|         \   *                               *   /         |
|          \    *                           *    /          |
|           \     *                       *     /           |
|            \   R u l e             R u l e   /            |
|             \       *               *       /             |
|              \        *           *        /              |
```

```
|                \         *       *         /                |
|                 \          * B *          /                 |
|               F a c t        o        F a c t               |
|                   \          *          /                   |
|                    \         *         /                    |
|                     \        *        /                     |
|                      \       *       /                      |
|                       \   C a s e   /                       |
|                        \     *     /                        |
|                         \    *    /                         |
|                          \   *   /                          |
|                           \  *  /                           |
|                            \ * /                            |
|                             \*/                             |
|                              o                              |
|                              C                              |
|                                                             |
| A  =  the Air is cool                                      |
| B  =  just Before it rains                                 |
| C  =  the Current situation                                |
| D  =  a Dark cloud appears                                 |
|                                                             |
| A is a major term                                          |
| B is a middle term                                         |
| C is a minor term                                          |
| D is a major term, associated with A                       |
|                                                             |
o-------------------------------------------------------------o
Figure 4.  Dewey's 'Rainy Day' Inquiry
```

In this analysis of the first steps of Inquiry, we have a complex or a mixed form of inference that can be seen as taking place in two steps:

- The first step is an Abduction that abstracts a Case from the consideration of a Fact and a Rule.

  Fact: C → A, In the Current situation the Air is cool.

  Rule: B → A, Just Before it rains, the Air is cool.

  Case: C → B, The Current situation is just Before it rains.

- The final step is a Deduction that admits this Case to another Rule and so arrives at a novel Fact.

  Case: C → B, The Current situation is just Before it rains.

  Rule: B → D, Just Before it rains, a Dark cloud will appear.

  Fact: C → D, In the Current situation, a Dark cloud will appear.

This is nowhere near a complete analysis of the Rainy Day inquiry, even insofar as it might be carried out within the constraints of the syllogistic framework, and it covers only the first two steps of the relevant inquiry process, but maybe it will do for a start.

One other thing needs to be noticed here, the formal duality between this expansion phase of inquiry and the argument from analogy. This can be seen most clearly in the propositional lattice diagrams shown in Figures 3 and 4, where analogy exhibits a rough "A" shape and the first two steps of inquiry exhibit a rough "V" shape, respectively.

Since we find ourselves repeatedly referring to this expansion phase of inquiry as a unit, let's give it a name that suggests its duality with analogy—"catalogy" will do for the moment. This usage is apt enough if one thinks of a catalogue entry for an item as a text that lists its salient features. Notice that analogy has to do with the examples of a given quality, while catalogy has to do with the qualities of a given example. Peirce noted similar forms of duality in many of his early writings, leading to the consummate treatment in his 1867 paper "On a New List of Categories" [1] (CP 1.545-559, W 2, 49-59).

Weeding hypotheses

In order to comprehend the bearing of inductive reasoning on the closing phases of inquiry there are a couple of observations that we need to make:

- First, we need to recognize that smaller inquiries are typically woven into larger inquiries, whether we view the whole pattern of inquiry as carried on by a single agent or by a complex community.
- Further, we need to consider the different ways in which the particular instances of inquiry can be related to ongoing inquiries at larger scales. Three modes of inductive interaction between the micro-inquiries and the macro-inquiries that are salient here can be described under the headings of the "Learning", the "Transfer", and the "Testing" of rules.

Analogy of experience

Throughout inquiry the reasoner makes use of rules that have to be transported across intervals of experience, from the masses of experience where they are learned to the moments of experience where they are applied. Inductive reasoning is involved in the learning and the transfer of these rules, both in accumulating a knowledge base and in carrying it through the times between acquisition and application.

- Learning. The principal way that induction contributes to an ongoing inquiry is through the learning of rules, that is, by creating each of the rules that goes into the knowledge base, or ever gets used along the way.
- Transfer. The continuing way that induction contributes to an ongoing inquiry is through the exploit of analogy, a two-step combination of induction and deduction that serves to transfer rules from one context to another.
- Testing. Finally, every inquiry that makes use of a knowledge base constitutes a "field test" of its accumulated contents. If the knowledge base fails to serve any live inquiry in a satisfactory manner, then there is a prima facie reason to reconsider and possibly to amend some of its rules.

Let's now consider how these principles of learning, transfer, and testing apply to John Dewey's "Sign of Rain" example.

Learning

Rules in a knowledge base, as far as their effective content goes, can be obtained by any mode of inference.

For example, a rule like:

- Rule: $B \to A$, Just Before it rains, the Air is cool,

is usually induced from a consideration of many past events, in a manner that can be rationally reconstructed as follows:

- Case: $C \to B$, In Certain events, it is just Before it rains,
- Fact: $C \to A$, In Certain events, the Air is cool,

- Rule: $B \to A$, Just Before it rains, the Air is cool.

However, the very same proposition could also be abduced as an explanation of a singular occurrence or deduced as a conclusion of a presumptive theory.

Transfer

What is it that gives a distinctively inductive character to the acquisition of a knowledge base? It is evidently the "analogy of experience" that underlies its useful application. Whenever we find ourselves prefacing an argument with the phrase "If past experience is any guide..." then we can be sure that this principle has come into play. We are invoking an analogy between past experience, considered as a totality, and present experience, considered as a point of application. What we mean in practice is this: "If past experience is a fair sample of possible experience, then the knowledge gained in it applies to present experience". This is the mechanism that allows a knowledge base to be carried across gulfs of experience that are indifferent to the effective contents of its rules.

Here are the details of how this notion of transfer works out in the case of the "Sign of Rain" example:

Let K(pres) be a portion of the reasoner's knowledge base that is logically equivalent to the conjunction of two rules, as follows:

- K(pres) = (B → A) and (B → D).

K(pres) is the present knowledge base, expressed in the form of a logical constraint on the present universe of discourse.

It is convenient to have the option of expressing all logical statements in terms of their logical models, that is, in terms of the primitive circumstances or the elements of experience over which they hold true.

- Let E(past) be the chosen set of experiences, or the circumstances that we have in mind when we refer to "past experience".
- Let E(poss) be the collective set of experiences, or the projective total of possible circumstances.
- Let E(pres) be the present experience, or the circumstances that are present to the reasoner at the current moment.

If we think of the knowledge base K(pres) as referring to the "regime of experience" over which it is valid, then all of these sets of models can be compared by the simple relations of set inclusion or logical implication.

Figure 5 schematizes this way of viewing the "analogy of experience".

```
o-----------------------------------------------------------o
|                                                           |
|                          K(pres)                          |
|                             o                             |
|                            /|\                            |
|                           / | \                           |
|                          /  |  \                          |
|                         /   |   \                         |
|                        /  Rule   \                        |
|                       /     |     \                       |
|                      /      |      \                      |
|                     /       |       \                     |
|                    /     E(poss)     \                    |
|              Fact /         o         \ Fact              |
|                  /        *   *        \                  |
|                 /       *       *       \                 |
|                /      *           *      \                |
|               /     *               *     \               |
|              /    *                   *    \              |
|             /   *  Case           Case  *   \             |
|            /  *                           *  \            |
```

```
|           / *                              * \          |
|          /*                                  *\         |
|         o<<<---------------<<<---------------<<<o        |
|       E(past)        Analogy Morphism         E(pres)    |
|     More Known                              Less Known  |
|                                                         |
o---------------------------------------------------------o
Figure 5.  Analogy of Experience
```

In these terms, the "analogy of experience" proceeds by inducing a Rule about the validity of a current knowledge base and then deducing a Fact, its applicability to a current experience, as in the following sequence:

Inductive Phase:

- Given Case: E(past) → E(poss), Chosen events fairly sample Collective events.
- Given Fact: E(past) → K(pres), Chosen events support the Knowledge regime.

- Induce Rule: E(poss) → K(pres), Collective events support the Knowledge regime.

Deductive Phase:

- Given Case: E(pres) → E(poss), Current events fairly sample Collective events.
- Given Rule: E(poss) → K(pres), Collective events support the Knowledge regime.

- Deduce Fact: E(pres) → K(pres), Current events support the Knowledge regime.

Testing

If the observer looks up and does not see dark clouds, or if he runs for shelter but it does not rain, then there is fresh occasion to question the utility or the validity of his knowledge base. But we must leave our foulweather friend for now and defer the logical analysis of this testing phase to another occasion.

Citations

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See also

- Charles Sanders Peirce bibliography
- C. West Churchman
- Curiosity
- Information entropy
- Information theory
- Logic of information
- Phronetic social science
- Pragmatic information
- Pragmatic theory of truth
- Pragmaticism
- Uncertainty

Knowledge

Knowledge is defined by the Oxford English Dictionary as (i) expertise, and skills acquired by a person through experience or education; the theoretical or practical understanding of a subject; (ii) what is known in a particular field or in total; facts and information; or (iii) awareness or familiarity gained by experience of a fact or situation. Philosophical debates in general start with Plato's formulation of knowledge as "justified true belief." There is however no single agreed definition of knowledge presently, nor any prospect of one, and there remain numerous competing theories. Knowledge acquisition involves complex cognitive processes: perception, learning, communication, association and reasoning. The term *knowledge* is also used to mean the confident understanding of a subject with the ability to use it for a specific purpose if appropriate. See knowledge management for additional details on that discipline.

Personification of knowledge (Greek *Επιστημη*, Episteme) in Celsus Library in Ephesus, Turkey.

Defining knowledge (philosophy)

Robert Reid, *Knowledge* (1896). Thomas Jefferson Building, Washington, D.C.

> We suppose ourselves to possess unqualified scientific knowledge of a thing, as opposed to knowing it in the accidental way in which the sophist knows, when we think that we know the cause on which the fact depends, as the cause of that fact and of no other, and, further, that the fact could not be other than it is. Now that scientific knowing is something of this sort is evident — witness both those who falsely claim it and those who actually possess it, since the former merely imagine themselves to be, while the latter are also actually, in the condition described. Consequently the proper object of unqualified scientific knowledge is something which cannot be other than it is.
>
> — Aristotle, Posterior Analytics (Book 1 Part 2)

The definition of knowledge is a matter of on-going debate among philosophers in the field of epistemology. The classical definition, described but not ultimately endorsed by Plato [1], specifies that a statement must meet three criteria in order to be considered knowledge: it must be justified, true, and believed. Some claim that these conditions are not sufficient, as Gettier case examples allegedly demonstrate. There are a number of alternatives proposed, including Robert Nozick's arguments for a requirement that knowledge 'tracks the truth' and Simon Blackburn's additional requirement that we do not want to say that those who meet any of these conditions 'through a defect, flaw, or failure' have knowledge. Richard Kirkham suggests that our definition of knowledge requires that the belief is self-evident to the believer.[2]

In contrast to this approach, Wittgenstein observed, following Moore's paradox, that one can say "He believes it, but it isn't so", but not "He knows it, but it isn't so". [3] He goes on to argue that these do not correspond to distinct mental states, but rather to distinct ways of talking about conviction. What is different here is not the mental state of the speaker, but the activity in which they are engaged. For example, on this account, to *know* that the kettle is boiling is not to be in a particular state of mind, but to perform a particular task with the statement that the kettle is boiling. Wittgenstein sought to bypass the difficulty of definition by looking to the way "knowledge" is used in natural languages. He saw knowledge as a case of a family resemblance. Following this idea, "knowledge" has been reconstructed as a cluster concept that points out relevant features but that is not adequately captured by any definition.[4]

Communicating knowledge

Symbolic representations can be used to indicate meaning and can be thought of as a dynamic process. Hence the transfer of the symbolic representation can be viewed as one ascription process whereby knowledge can be transferred. Other forms of communication include imitation, narrative exchange along with a range of other methods. There is no complete theory of knowledge transfer or communication.

While many would agree that one of the most universal and significant tools for the transfer of knowledge is writing (of many kinds), argument over the usefulness of the written word exists however, with some scholars skeptical of its impact on societies. In his collection of essays *Technopoly* Neil Postman demonstrates the argument against the use of writing through an excerpt from Plato's work *Phaedrus* (Postman, Neil (1992) *Technopoly*, Vintage, New York, pp 73). In this excerpt the scholar Socrates recounts the story of Thamus, the Egyptian king and Theuth the inventor of the written word. In this story, Theuth presents his new invention "writing" to King Thamus, telling Thamus that his new invention "will improve both the wisdom and memory of the Egyptians" (Postman, Neil (1992) Technopoly, Vintage, New York, pp 74). King Thamus is skeptical of this new invention and rejects it as a tool of recollection rather than retained knowledge. He argues that the written word will infect the Egyptian people with fake knowledge as they will be able to attain facts and stories from an external source and will no longer be forced to mentally retain large quantities of knowledge themselves (Postman, Neil (1992) *Technopoly*, Vintage, New York ,pp 74).

Andrew Robinson also highlights, in his work *The Origins of Writing*, the possibility for writing to be used to spread false information and therefore the ability of the written word to decrease social knowledge (Robinson, Andrew (2003) *The Origins of Writing* in Crowley and Heyer (eds) Communication in History: Technology, Culture, Society, Boston pp 34). People are often internalizing new information which they perceive to be knowledge but in reality fill their minds with false knowledge.

Situated knowledge

Situated knowledge is knowledge specific to a particular situation.

Some methods of generating knowledge, such as trial and error, or learning from experience, tend to create highly situational knowledge. One of the main benefits of the scientific method is that the theories it generates are much less situational than knowledge gained by other methods. Situational knowledge is often embedded in language, culture, or traditions.

Knowledge generated through experience is called knowledge "a posteriori", meaning afterwards. The pure existence of a term like "a posteriori" means this also has a counterpart. In this case that is knowledge "a priori", meaning before. The knowledge prior to any experience means that there are certain "assumptions" that one takes for granted. For example if you are being told about a chair it is clear to you that the chair is in space, that it is 3D. This knowledge is not knowledge that one can "forget", even someone suffering from amnesia experiences the world in 3D. See also: *a priori and a posteriori*.

Partial knowledge

One discipline of epistemology focuses on partial knowledge. In most realistic cases, it is not possible to have an exhaustive understanding of an information domain, so then we have to live with the fact that our knowledge is always *not complete*, that is, partial. Most real problems have to be solved by taking advantage of a partial understanding of the problem context and problem data. That is very different from the typical simple maths problems one might solve at school, where all data is given and one has a perfect understanding of formulas necessary to solve them.

This idea is also present in the concept of bounded rationality which assumes that in real life situations people often have a limited amount of information and make decisions accordingly.

Scientific knowledge

The development of the scientific method has made a significant contribution to our understanding of knowledge. To be termed scientific, a method of inquiry must be based on gathering observable, empirical and measurable evidence subject to specific principles of reasoning.[5] The scientific method consists of the collection of data through observation and experimentation, and the formulation and testing of hypotheses.[6] . Science, and the nature of scientific knowledge have also become the subject of Philosophy. As science itself has developed, knowledge has developed a broader usage which has been developing within biology/psychology—discussed elsewhere as meta-epistemology, or genetic epistemology, and to some extent related to "theory of cognitive development".

Sir Francis Bacon, "Knowledge is Power"

Note that "epistemology" is the study of knowledge and how it is acquired. Science is “the process used everyday to logically complete thoughts through inference of facts determined by calculated experiments." Sir Francis Bacon, critical in the historical development of the scientific method, his works established and popularized an inductive methodology for scientific inquiry. His famous aphorism, "knowledge is power", is found in the Meditations Sacrae (1597).[7] .

Until recent times, at least in the Western tradition, it was simply taken for granted that knowledge was something possessed only by humans — and probably *adult* humans at that. Sometimes the notion might stretch to (ii) *Society-as-such*, as in (e.g.) "the knowledge possessed by the Coptic culture" (as opposed to its individual members), but that was not assured either. Nor was it usual to consider *unconscious* knowledge in any systematic way until this approach was popularized by Freud. [8]

Other biological domains where "knowledge" might be said to reside, include: (iii) the *immune system*, and (iv) in the *DNA of the genetic code*. See the list of four "epistemological domains": Popper, (1975)[9] ; and Traill (2008 [10]: Table S, page 31)—also references by both to Niels Jerne.

Such considerations seem to call for a separate definition of "knowledge" to cover the biological systems. For biologists, knowledge must be usefully *available* to the system, though that system need not be conscious. Thus the criteria seem to be:

- The system should apparently be dynamic and self-organizing (unlike a mere book *on its own*).

- The knowledge must constitute some sort of representation of "the outside world"[11] , or ways of dealing with it (directly or indirectly).
- There must be some way for the system to access this information quickly enough for it to be useful.

Scientific knowledge may not involve a claim to certainty, maintaining skepticism means that a scientist will never be absolutely certain when they are correct and when they are not. It is thus an irony of proper scientific method that one must doubt even when correct, in the hopes that this practice will lead to greater convergence on the truth in general.[12]

Religious meaning of knowledge

In many expressions of Christianity, such as Catholicism and Anglicanism, knowledge is one of the seven gifts of the Holy Spirit.[13]

In Islam, knowledge (Arabic: علم, *ʿilm*) is given great significance. "The All-Knowing" (*al-ʿAlīm*) is one of the 99 names reflecting distinct attributes of God. The Qur'an asserts that knowledge comes from God (2:239) and various *hadith* encourage the acquisition of knowledge. Muhammad is reported to have said "Seek knowledge from the cradle to the grave" and "Verily the men of knowledge are the inheritors of the prophets". Islamic scholars, theologians and jurists are often given the title *alim*, meaning "knowledgable".

Hindu Scriptures present two kinds of knowledge, *Paroksha Gnyana* and *Aporoksha Gnyana*. *Paroksha Gnyana* (also spelled *Paroksha-Jnana*) is secondhand knowledge: knowledge obtained from books, hearsay, etc. *Aporoksha Gnyana* (also spelled *Aparoksha-Jnana*) is the knowledge borne of direct experience, i.e., knowledge that one discovers for oneself.[14]

The Old Testament's tree of the knowledge of good and evil contained the knowledge that separated Man from God: "And the LORD God said, Behold, the man is become as one of us, to know good and evil…" (Genesis 3:22)

In Gnosticism divine knowledge or gnosis is hoped to be attained and escape from the demiurge's physical world. And in Thelema knowledge and conversation with one's Holy Guardian Angel is the purpose of life, which is similar to Gnosis or enlightenment in other mystery religions.

See also

- Analytic-synthetic distinction
- Descriptive knowledge
- Epistemic logic
- Epistemology (theory of knowledge)
- Explicit knowledge
- Figurative system of human knowledge
- Intelligence
- Intuition as an unconscious form of knowledge.
- Knowledge discovery
- Knowledge engineering
- Knowledge management
- Knowledge relativity
- Knowledge communication
- Knowledge retrieval
- Learning
- Metaknowledge
- Philosophical skepticism
- Procedural knowledge
- Propædia (outline of human knowledge)
- Society for the Diffusion of Useful Knowledge
- Scientia potentia est/ (knowledge is power)
- Tacit knowledge
- Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities
- Wisdom
- Hard knowledge and Soft knowledge

Notes

[1] In Plato's *Theaetetus*, Socrates and Theaetetus discuss three definitions of *knowledge*: knowledge as nothing but perception, knowledge as true judgment, and, finally, knowledge as a true judgment with an account. Each of these definitions is shown to be unsatisfactory.

[2] http://www.centenary.edu/attachments/philosophy/aizawa/courses/epistemologyf2008/kirkham1984.pdf

[3] Ludwig Wittgenstein, *On Certainty*, remark 42

[4] Gottschalk-Mazouz, N. (2008): „Internet and the flow of knowledge“, in: Hrachovec, H.; Pichler, A. (Hg.): Philosophy of the Information Society. Proceedings of the 30. International Ludwig Wittgenstein Symposium Kirchberg am Wechsel, Austria 2007. Volume 2, Frankfurt, Paris, Lancaster, New Brunswik: Ontos, S. 215-232. http://www.uni-stuttgart.de/philo/fileadmin/doc/pdf/gottschalk/ngm-internetflow-2008.pdf

[5] "[4] Rules for the study of natural philosophy", Newton 1999, pp. 794–6, from the General Scholium, which follows Book **3**, *The System of the World*.

[6] scientific method (http://www.m-w.com/dictionary/scientific method), *Merriam-Webster Dictionary*.

[7] "Sir Francis Bacon - Quotationspage.com" (http://www.quotationspage.com/quote/2060.html). . Retrieved 2009-07-08.

[8] There is quite a good case for this exclusive specialization used by philosophers, in that it allows for in-depth study of logic-procedures and other abstractions which are not found elsewhere. However this may lead to problems whenever the topic spills over into those excluded domains—e.g. when Kant (following Newton) dismissed *Space and Time* as axiomatically "transcendental" and "a priori" — a claim later disproved by Piaget's clinical studies. It also seems likely that the vexed problem of "*infinite regress*" can be largely (but not completely) solved by proper attention to how unconscious concepts are *actually* developed, both during infantile learning *and* as inherited "pseudo-transcendentals" inherited from the trial-and-error of previous generations. See also "Tacit knowledge".

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[9] Popper, K.R. (1975). "The rationality of scientific revolutions"; in Rom Harré (ed.), *Problems of Scientific Revolution: Scientific Progress and Obstacles to Progress in the Sciences*. Clarendon Press: Oxford.

[10] http://www.ondwelle.com/OSM02.pdf

[11] This "outside world" could include other subsystems within the same organism—e.g. different "mental levels" corresponding to different Piagetian stages. See Theory of cognitive development.

[12] http://philosophybites.com/2007/12/barry-stroud-on.html

[13] "Part Three, No. 1831" (http://www.scborromeo.org/ccc/p3s1c1a7.htm#1831). *Catechism of the Catholic Church*. . Retrieved 2007-04-20.

[14] Swami Krishnananda. "Chapter 7" (http://www.swami-krishnananda.org/panch/panch_07.html). *The Philosophy of the Panchadasi*. The Divine Life Society. . Retrieved 2008-07-05.

Logical consequence

"Therefore" redirects here. For the symbol, see therefore sign.

Logical consequence is a fundamental concept in logic. It is the relation that holds between a set of sentences (or propositions) and a sentence (proposition) when the former "entails" the latter. For example, 'Kermit is green' is said to be a logical consequence of 'All frogs are green' and 'Kermit is a frog', because it would be "self-contradictory" to affirm the latter and deny the former. Logical consequence is the relationship between the premises and the conclusion of a valid argument. These explanations and definitions tend to be circular; the provision of a satisfactory account of **logical consequence** and **entailment** is an important topic of philosophy of logic.

The truth of the above consequence depends on both the truth of the antecedents and the relationship of logical consequence between the antecedents and the consequence. The consequence might NOT be true if not all frogs were green. Logical consequences or inferences by deductive reasoning are a major aspect of epistemology that communicates to the general public hypotheses about causality of risk factors.

A formally specified logical consequence relation may be characterized model-theoretically or proof-theoretically (or both).

Logical consequence can also be expressed as a function from sets of sentences to sets of sentences (Tarski's preferred formulation), or as a relation between two sets of sentences (multiple-conclusion logic).

Accounts of logical consequence

This section describes some common accounts of logical consequence.

Γ will represent an arbitrary set of premises and A an arbitrary conclusion. Γ/A will denote the logical argument having Γ as its (set of) premises and A as its conclusion. $\Gamma \models A$ will mean that A is a logical consequence of Γ.

Formal consequence

Formal accounts of logical consequence are variations on the following basic idea:

- $\Gamma \models A$ just in case no argument with the same logical form as Γ/A has true premises and a false conclusion.

Two common variations on this basic idea are:

1. $\Gamma \models A$ just in case no uniform substitution of the nonlogical terms in Γ/A yields an argument with true premises and a false conclusion.
2. $\Gamma \models A$ just in case there is no way of interpreting the nonlogical terms in Γ/A that yields an argument with true premises and a false conclusion.

Let us again consider the argument:

All frogs are green.

Kermit is a frog.

Therefore, Kermit is green.

Formal account (1) says that the conclusion is a logical consequence of the premises because no matter how we uniformly replace the nonlogical terms (*frog*, *green*, *Kermit*) in the argument, we do not get true premises and a false conclusion. Consider for example:

All skyscrapers are tall.

The Empire State Building is a skyscraper.

Therefore, the Empire State Building is tall.

All squares are rectangles.

All rectangles are quadrilaterals.

Therefore, a square is a quadrilateral.

All matter has mass.

Coffee tables are matter.

Therefore, coffee tables have mass.

All birds have feathers.

Penguins are birds.

Therefore, penguins have feathers.

We can make up arguments of this form all day, but we will never come up with one that has true premises and a false conclusion. The argument is deductively valid by virtue of its logical form, which might be characterized with the following template (in which **F**, **G**, and **a** are meaningless placeholders):

All **F**s are **G**s.

a is an **F**.

Therefore, **a** is a **G**.

Formal account (2) says that the conclusion of the "Kermit" argument is a logical consequence of the premises because no matter how we *interpret* the nonlogical terms (*frog*, *green*, *Kermit*) in the argument, we do not get true premises and a false conclusion. Suppose, for example, we interpret *frog* to mean *plumber*, *green* to mean *shy*, and *Kermit* to mean *Madonna* (the singer). Then the argument has two false premises (for not all plumbers are shy, and Madonna is not a plumber) and a false conclusion (for Madonna is not shy). We can come up with as many interpretations of *frog*, *green*, and *Kermit* as we like, but this will never result in an argument with true premises and a false conclusion.

Syntactic consequence

A formula A is a **syntactic consequence**[1] [2] [3] [4] within some formal system FS of a set Γ of formulas if there is a formal proof in FS of A from the set Γ.

$$\Gamma \vdash_{FS} A$$

Syntactic consequence does not depend on any interpretation of the formal system.[5]

Semantic consequence

A formula A is a **semantic consequence** of a set of statements Γ

$$\Gamma \models A,$$

if and only if no interpretation $\mathcal{I}$ makes all members of Γ true and A false.[6]

Modal accounts

Modal accounts of logical consequence are variations on the following basic idea:

- $\Gamma \vdash A$ just in case it is *necessary* that if all of the elements of Γ are true, then *A* is true.

Alternatively (and, most would say, equivalently):

- $\Gamma \vdash A$ just in case it is *impossible* for all of the elements of Γ to be true and *A* false.

Such accounts are called "modal" because they appeal to the modal notions of necessity and (im)possibility. 'It is necessary that' is often cashed out as a universal quantifier over possible worlds, so that the accounts above translate as:

- $\Gamma \vdash A$ just in case there is no possible world at which all of the elements of Γ are true and *A* is false (untrue).

Consider the modal account in terms of the argument given as an example above:

All frogs are green.

Kermit is a frog.

Therefore, Kermit is green.

The conclusion is a logical consequence of the premises because we can't imagine a possible world where (a) all frogs are green; (b) Kermit is a frog; and (c) Kermit is not green.

Modal-formal accounts

Modal-formal accounts of logical consequence combine the modal and formal accounts above, yielding variations on the following basic idea:

- $\Gamma \vdash A$ just in case it is impossible for an argument with the same logical form as Γ/A to have true premises and a false conclusion.

Most logicians would probably agree that logical consequence, as we intuitively understand it, has both a modal and a formal aspect, and that some version of the modal/formal account is therefore closest to being correct.

Warrant-based accounts

The accounts considered above are all "truth-preservational," in that they all assume that the characteristic feature of a good inference is that it never allows one to move from true premises to an untrue conclusion. As an alternative, some have proposed "warrant-preservational" accounts, according to which the characteristic feature of a good inference is that it never allows one to move from justifiably assertible premises to a conclusion that is not justifiably assertible. This is (roughly) the account favored by intuitionists such as Michael Dummett.

Non-monotonic logical consequence

The accounts discussed above all yield monotonic consequence relations, i.e. ones such that if A is a consequence of Γ, then A is a consequence of any superset of Γ. It is also possible to specify non-monotonic consequence relations to capture the idea that, e.g., 'Tweety can fly' is a logical consequence of

{Birds can typically fly, Tweety is a bird}

but not of

{Birds can typically fly, Tweety is a bird, Tweety is a penguin}.

For more on this, see the article on non-monotonic logic.

See also

- Deductive reasoning
- Tautology (logic)
- Validity
- Turnstile (symbol)
- Double turnstile

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[2] http://books.google.com/books?id=lXI7AAAAIAAJ&pg=PA1&lpg=PA1&dq=syntactic+consequence&source=bl&ots=8IYWyFYTN-&sig=wrOg75cFxQwn1Uq-8LShBNXf9w0&hl=en&ei=I-y7SpHtLZLotgOsnLHcBQ&sa=X&oi=book_result&ct=result&resnum=10#v=onepage&q=syntactic%20consequence&f=false
[3] http://books.google.com/books?id=87BcFLgJmxMC&pg=PA189&lpg=PA189&dq=syntactic+consequence&source=bl&ots=Fn2zomcMZP&sig=8hnJWsJFysNhmWLskICo4IQDYAc&hl=en&ei=I-y7SpHtLZLotgOsnLHcBQ&sa=X&oi=book_result&ct=result&resnum=6#v=onepage&q=syntactic%20consequence&f=false
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External links

- Stanford Encyclopedia of Philosophy (http://plato.stanford.edu/entries/logical-consequence/)
- Internet Encyclopedia of Philosophy (http://www.iep.utm.edu/l/logcon.htm)

Observation

Observation is either an activity of a living being (such as a human), consisting of receiving knowledge of the outside world through the senses, or the recording of data using scientific instrument. The term may also refer to any data collected during this activity. An observation can also be the way you look at things or when you look at something.

Observation in science

The scientific method requires observations of nature to formulate and test hypotheses. It consists of these steps:

1. Asking a question about a natural phenomenon
2. Making observations of the phenomenon
3. Hypothesizing an explanation for the phenomenon
4. Predicting a logical consequence of the hypothesis
5. Testing the hypothesis by an experiment, an observational study, or a field study
6. Creating a conclusion with data gathered in the experiment

Observation plays a role in the second and fifth steps. However the need for reproducibility requires that observations by different observers be comparable. Human sense impressions are subjective and qualitative making them difficult to record or compare. The idea of measurement evolved to allow recording and comparison of observations made at different times and places by different people. Measurement consists of using observation to compare the thing being measured to a standard; an artifact, process or definition which can be duplicated or shared by all observers, and counting how many of the standard units are comparable to the object. Measurement reduces an observation to a number which can be recorded, and two observations which result in the same number are equal within the resolution of the process.

Senses are limited, and are subject to errors in perception such as optical illusions. Scientific instruments were developed to magnify human powers of observation, such as weighing scales, clocks, telescopes, microscopes, thermometers, cameras, and tape recorders, and also translate into perceptible form events that are unobservable by human senses, such as indicator dyes, voltmeters, spectrometers, infrared cameras, oscilloscopes, interferometers, geiger counters, x-ray machines, and radio receivers.

One problem encountered throughout scientific fields is that the observation may affect the process being observed, resulting in a different outcome than if the process was unobserved. This is called the *observer effect*. For example, it is not normally possible to check the air pressure in an automobile tire without letting out some of the air, thereby changing the pressure. However, in most fields of science it is possible to reduce the effects of observation to insignificance by using better instruments.

Considered as a physical process itself, all forms of observation (human or instrumental) involve amplification and are thus thermodynamically irreversible processes, increasing entropy.

Alternative definitions

In some specific fields of science the words "observer" and "observation" have to be redefined to take into account factors that don't seem so important in everyday observation:

- **Relativity:** In relativistic physics which deals with velocities close to the speed of light, it is found that different observers may observe different values for the length, time rates, mass, and many other properties of an object, depending on the observer's velocity relative to the object. Therefore an observation must always be qualified by specifying the state of motion of the observer, his reference frame.

- **Quantum mechanics:** In quantum mechanics, which deals with the behavior of very small objects, it is not possible to observe a system without changing the system, and the "observer" must be considered part of the system being observed. In isolation, quantum objects are represented by a wavefunction which often exists in a superposition or mixture of different states. However, when an observation is made to determine the actual location or state of the object, it always finds the object in a single state, not a "mixture". The interaction of the observation process appears to "collapse" the wavefunction into a single state. So any interaction between an isolated wavefunction and the external world that results in this wavefunction collapse is called an *observation* or *measurement*, whether or not it is part of a deliberate observation process.

Biases

Observational bias

An observational bias occurs when researchers only look where they think they will find positive results, or where it is easy to record observations. This is called the "streetlight effect".[1]

Confirmation bias

Human observations are biased toward confirming the observer's conscious and unconscious expectations and view of the world; we "*see what we expect to see*". In psychology, this is called confirmation bias. Since the object of scientific research is the discovery of new phenomena, this bias can and has caused new discoveries to be overlooked. One example is the discovery of x-rays. It can also result in erroneous scientific support for widely held cultural myths, for example the scientific racism that supported ideas of racial superiority in the early 20th century, and creation science today. Correct scientific technique emphasizes careful recording of observations, separating experimental observations from the conclusions drawn from them, and techniques such as blind or double blind experiments, to minimize observational bias.

"Cargo cult" science

Another bias, which has become more prevalent with the advent of "big science" and the large rewards of new discoveries, is bias in favor of the researcher's favorite hypothesis; we "*see what we want to see*". Called pathological science and cargo cult science, this is different from deliberate falsification of results, and can happen to good-faith researchers. Possible examples of mistaken discoveries caused by this bias are Martian "canals", N rays, polywater, and cold fusion. Recent decades have seen scientific scandals caused by researchers playing "fast and loose" with observational methods in order to get their pet theories published. This type of bias is rampant in pseudoscience, where correct scientific techniques are not followed. The main defense against this bias, besides correct research techniques, is peer review and repetition of the experiment, or the observation, by other researchers with no incentive to bias. For example, an emerging practice in the competitive field of biotechnology is to require the physical results of experiments, such as serums and tissue cultures, be made available to competing laboratories for independent testing.

Processing bias

Modern scientific instruments can extensively process "observations" before they are presented to the human senses, and particularly with computerized instruments, there is sometimes a question as to where in the *measurement chain* "observing" ends and "drawing conclusions" begins. This has recently become an issue with digitally enhanced images published as experimental data in papers in scientific journals. The images are enhanced to bring out features that the researcher wants to emphasize, but this also has the effect of supporting his conclusions. This is a form of bias that is difficult to quantify. Some scientific journals have begun to set detailed standards for what types of image processing are allowed in research results. Computerized instruments often keep a copy of the "raw data" from sensors before processing, which is the ultimate defense against processing bias, and similarly scientific standards require preservation of the original unenhanced "raw" versions of images used as research data.

Observations in philosophy

> "Observe always that everything is the result of a change, and get used to thinking that there is nothing Nature loves so well as to change existing forms and to make new ones like them."
>
> —Meditations. iv. 36. – Marcus Aurelius

Observation in philosophical terms is the process of filtering sensory information through the thought process. Input is received via hearing, sight, smell, taste, or touch and then analyzed through either rational or irrational thought. You *see* a parent beat their child; you *observe* that such an action is either good or bad. Deductions about what behaviors are good or bad may be based in no way on preferences about building relationships, or study of the consequences resulting from the observed behavior. With the passage of time, impressions stored in the consciousness about many related observations, together with the resulting relationships and consequences, permit the individual to build a construct about the moral implications of behavior.

The defining characteristic of observation is that it involves drawing conclusions, as well as building personal views about how to handle similar situations in the future, rather than simply registering that something has happened. However, observation according to Jiddu Krishnamurti does not necessarily imply drawing conclusions and building personal views. Instead of the accumulation of knowledge, a time-based, conditioning function he identified with the past, he stressed observation as a continuous process of learning, a timeless process that happens always in the present. Such observation, he asserted, frees the mind of its conditioning by discarding psychological dependence on the past.

See also

- Introspection
- List of cognitive biases
- Naturalistic observation
- Observational learning
- Observations and Measurements
- Observer effect
- Uncertainty principle
- Observational science
- Observational astronomy
- Observatory

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[1] David H. Freedman (August 1, 2010). "The Streetlight Effect". *Discover magazine*.

Piaget's theory of cognitive development

Piaget's theory of cognitive development is a comprehensive theory about the nature and development of human intelligence first developed by Jean Piaget. It is primarily known as a developmental stage theory, but in fact, it deals with the nature of knowledge itself and how humans come gradually to acquire it, construct it, and use it. Moreover, Piaget claims the idea that cognitive development is at the centre of human organism and language is contingent on cognitive development. Below, there is first a short description of Piaget's views about the nature of intelligence and then a description of the stages through which it develops until maturity.

The Nature of Intelligence: Operative and Figurative Intelligence

Piaget believed that reality is a dynamic system of continuous change, and as such is defined in reference to the two conditions that define dynamic systems that change. Specifically, he argued that reality involves transformations and states. Transformations refer to all manners of changes that a thing or person can undergo. States refer to the conditions or the appearances in which things or persons can be found between transformations. For example, there might be changes in shape or form (for instance, liquids are reshaped as they are transferred from one vessel to another, humans change in their characteristics as they grow older), in size (e.g., a series of coins on a table might be placed close to each other or far apart) in placement or location in space and time (e.g., various objects or persons might be found at one place at one time and at a different place at another time). Thus, Piaget argued, that if human intelligence is to be adaptive, it must have functions to represent both the transformational and the static aspects of reality. He proposed that operative intelligence is responsible for the representation and manipulation of the dynamic or transformational aspects of reality and that figurative intelligence is responsible for the representation of the static aspects of reality).[1]

Operative intelligence is the active aspect of intelligence. It involves all actions, overt or covert, undertaken in order to follow, recover, or anticipate the transformations of the objects or persons of interest. Figurative intelligence is the more or less static aspect of intelligence, involving all means of representation used to retain in mind the states (i.e., successive forms, shapes, or locations) that intervene between transformations. That is, it involves perception, imitation, mental imagery, drawing, and language. Therefore, the figurative aspects of intelligence derive their meaning from the operative aspects of intelligence, because states cannot exist independently of the transformations that interconnect them. Piaget believed that the figurative or the representational aspects of intelligence are subservient to its operative and dynamic aspects, and therefore, that understanding essentially derives from the operative aspect of intelligence.

At any time, operative intelligence frames how the world is understood and it changes if understanding is not successful. Piaget believed that this process of understanding and change involves two basic functions: Assimilation and accommodation. Assimilation refers to the active transformation of information so as to be integrated into the mental schemes already available. Its analog at the biological level might be the transformation of food by chewing and digestion to fit in with the structural and bio-chemical characteristics of the human body. Accommodation refers to the active transformation of these schemes so as to take into account the particularities of the objects, persons, or events the thinker is interacting with. Its analog at the biological level might be the adaptation of eating and digestion to the particulars of the different kinds of food we eat. For Piaget, none of these functions can exist without the other. To assimilate an object into an existing mental scheme, one first needs to take into account or accommodate to the particularities of this object to a certain extent; for instance, to recognize (assimilate) an apple as an apple one needs first to focus (accommodate) on the contour of this object. To do this one needs to roughly recognize the size of the object. We will see below that development increases the balance or equilibration between these two functions. When in balance with each other, they generate mental schemes of the operative intelligence. When the one dominates over the other, they generate representations which belong to figurative intelligence.

Following from this conception Piaget theorized that intelligence is active and constructive. In fact, it is active even in the literal sense of the term as it depends on the actions (overt or covert, assimilatory or accommodatory), which the thinker executes in order to build and rebuild his models of the world. And it is constructive because actions, particularly mental actions, are coordinated into more inclusive and cohesive systems and thus they are raised to ever more stable and effective levels of functioning. Piaget believed that this process of construction leads to systems of mental operations better able to resist the illusions of perceptual appearances and thus less prone to error. In other words, the gradual construction of the system of mental operations involved in the operative aspect of intelligence enables the developing person to grasp ever more hidden and complex aspects of the world. Below we will summarize the development of operative intelligence.

Piaget's four stages

According to Jean Piaget's theory of cognitive development, intelligence is the basic mechanism of ensuring equilibrium in the relations between the person and the environment. This is achieved through the actions of the developing person on the world. At any moment in development, the environment is assimilated in the schemes of action that are already available and these schemes are transformed or accommodated to the peculiarities of the objects of the environment plus of the surroundings and entire universe, if they are not completely appropriate. Thus, the development of intelligence is a continuous process of assimilations and accommodations that lead to increasing expansion of the field of application of schemes, increasing coordination between them, increasing interiorization, and increasing abstraction. The mechanism underlying this process of increasing abstraction, interiorization, and coordination is reflecting abstraction. That is, reflecting abstraction gradually leads to the rejection of the external action components of sensorimotor operations on objects and to the preservation of the mental, planning or anticipatory, components of operation. These are the mental operations that are gradually coordinated with each other, generating structures of mental operations. These structures of mental operations are applied on representations of objects rather than on the objects themselves. Language, mental images, and numerical notation are examples of representations standing for objects and thus they become the object of mental operations. Moreover, mental operations, with development, become reversible. For instance, the counting of a series of objects can go both forward and backward with the understanding that the number of objects counted is not affected by the direction of counting because the *same* number can be retrieved both ways.[2] Piaget described four main periods in the development towards completely reversible equlibrated thought structures. These are the periods described below. As shown below, for Piaget intelligence is not the same at different ages. It changes qualitatively, attaining increasingly broader, more abstract, and more equilibrated structures thereby allowing access to different levels of organization of the world.

Sensorimotor stage

The **sensorimotor stage** is the first of the four stages of cognitive development. "In this stage, infants construct an understanding of the world by coordinating sensory experiences (such as seeing and hearing) with physical, motoric actions. Infants gain knowledge of the world from the physical actions they perform on it. An infant progresses from reflexive, instinctual action at birth to the beginning of symbolic thought toward the end of the stage. Piaget divided the sensorimotor stage into six sub-stages"[3] :

Sub-Stage	Age	Description
1 *Simple Reflexes*	Birth-6 weeks	"Coordination of sensation and action through reflexive behaviors".[3] Three primary reflexes are described by Piaget: sucking of objects in the mouth, following moving or interesting objects with the eyes, and closing of the hand when an object makes contact with the palm (palmar grasp). Over the first six weeks of life, these reflexes begin to become voluntary actions; for example, the palmar reflex becomes intentional grasping.[4]).
2 *First habits and primary circular reactions phase*	6 weeks-4 months	"Coordination of sensation and two types of schemes: habits (reflex) and primary circular reactions (reproduction of an event that initially occurred by chance). Main focus is still on the infant's body." [3] As an example of this type of reaction, an infant might repeat the motion of passing their hand before their face. Also at this phase, passive reactions, caused by classical or operant conditioning, can begin.[4]
3 *Secondary circular reactions phase*	4–8 months	Development of habits. "Infants become more object-oriented, moving beyond self-preoccupation; repeat actions that bring interesting or pleasurable results."[3] This stage is associated primarily with the development of coordination between vision and prehension. Three new abilities occur at this stage: intentional grasping for a desired object, secondary circular reactions, and differentiations between ends and means. At this stage, infants will intentionally grasp the air in the direction of a desired object, often to the amusement of friends and family. Secondary circular reactions, or the repetition of an action involving an external object begin; for example, moving a switch to turn on a light repeatedly. The differentiation between means and ends also occurs. This is perhaps one of the most important stages of a child's growth as it signifies the dawn of logic.[4]
4 *Coordination of secondary circular reactions stage*	8–12 months	"Coordination of vision and touch--hand-eye coordination; coordination of schemes and intentionality." [3] This stage is associated primarily with the development of logic and the coordination between means and ends. This is an extremely important stage of development, holding what Piaget calls the "first proper intelligence." Also, this stage marks the beginning of goal orientation, the deliberate planning of steps to meet an objective.[4]
5 *Tertiary circular reactions, novelty, and curiosity*	12–18 months	"Infants become intrigued by the many properties of objects and by the many things they can make happen to objects; they experiment with new behavior." [3] This stage is associated primarily with the discovery of new means to meet goals. Piaget describes the child at this juncture as the "young scientist," conducting pseudo-experiments to discover new methods of meeting challenges.[4]
6 *Internalization of Schemes*	18–24 months	"Infants develop the ability to use primitive symbols and form enduring mental representations." [3] This stage is associated primarily with the beginnings of insight, or true creativity. This marks the passage into the preoperational stage.

"By the end of the sensorimotor period, objects are both separate from the self and permanent."[3] "Object permanence is the understanding that objects continue to exist even when they cannot be seen, heard, or touched."[3] "Acquiring the sense of object permanence is one of the infant's most important accomplishments, according to Piaget."[3]

Preoperational stage

The preoperative stage is the second of four stages of cognitive development.[5] By observing sequences of play, Piaget was able to demonstrate that towards the end of the second year, a qualitatively new kind of psychological functioning occurs.

(Pre)Operatory Thought is any procedure for mentally acting on objects. The hallmark of the preoperational stage is sparse and logically inadequate mental operations. During this stage, the child learns to use and to represent objects by images, words, and drawings.[5] The child is able to form stable concepts as well as mental reasoning and magical beliefs.[5] The child however is still not able to perform operations; tasks that the child can do mentally rather than physically.[5] Thinking is still egocentric: The child has difficulty taking the viewpoint of others. Two substages can be formed from preoperative thought.[5]

- **The Symbolic Function Substage**

Occurs between about the ages of 2 and 7.[5] The child is able to formulate designs of objects that are not present.[5] Other examples of mental abilities are language and pretend play.[5] Although there is an advancement in progress, there are still limitations such as egocentrism and animism.[5] Egocentrism occurs when a child is unable to distinguish between their own perspective and that of another person's.[5] Children tend to pick their own view of what they see rather than the actual view shown to others.[5] An example is an experiment performed by Piaget and Barbel Inhelder.[5] Three views of a mountain are shown and the child is asked what a traveling doll would see at the various angles; the child picks their own view compared to the actual view of the doll.[5] Animism is the belief that inanimate objects are capable of actions and have lifelike qualities.[5] An example is a child believing that the sidewalk was mad and made them fall down.[5]

- **The Intuitive Thought Substage**

  Occurs between about the ages of 2 and 7.[5] Children tend to become very curious and ask many questions; begin the use of primitive reasoning.[5] There is an emergence in the interest of reasoning and wanting to know why things are the way they are.[5] Piaget called it the intuitive substage because children realize they have a vast amount of knowledge but they are unaware of how they know it.[5] Centration and **conservation** are both involved in preoperative thought.[5] Centration is the act of focusing all attention on one characteristic compared to the others.[5] Centration is noticed in conservation; the awareness that altering a substance's appearance does not change its basic properties.[5] Children at this stage are unaware of conservation.[5] [5] In Piaget's most famous task, a child is presented with two identical beakers containing the same amount of liquid.[5] The child usually notes that the beakers have the same amount of liquid.[5] When one of the beakers is poured into a taller and thinner container, children who are typically younger than 7 or 8 years old say that the two beakers now contain a different amount of liquid.[5] The child simply focuses on the height and width of the container compared to the general concept.[5] Piaget believes that if a child fails the conservation-of-liquid task, it is a sign that they are at the preoperational stage of cognitive development.[5] The child also fails to show conservation of number, matter, length, volume, and area as well.[5] Another example is when a child is shown 7 dogs and 3 cats and asked if there are more dogs than cats. The child would respond positively. However when asked if there are more dogs than animals, the child would once again respond positively. Such fundamental errors in logic show the transition between intuitiveness in solving problems and true logical reasoning acquired in later years when the child grows up.

Piaget considered that children primarily learn through imitation and play throughout these first two stages, as they build up symbolic images through internalized activity.[6] [7]

Studies have been conducted among other countries to find out if Piaget's theory is universal.[5] Psychologist Patricia Greenfield conducted a task similar to Piaget's beaker experiment in the West African nation of Senegal.[5] Her results stated that only 50 percent of the 10-13 year old understood the concept of conservation.[5] Other cultures such as central Australia and New Guinea had similar results.[5] If adults had not gained this concept, they would be unable to understand the point of view of another person.[5] There may have been discrepancies in the communication between the experimenter and the children which may have altered the results.[5] It has also been found that if conservation is not widely practiced in a particular country, the concept can be taught to the child and training can improve the child's understanding.[5] Therefore, it is noted that there are different age differences in reaching the understanding of conservation based on the degree to which the culture teaches these tasks.[5]

Concrete operational stage

The **concrete operational stage** is the third of four stages of cognitive development in Piaget's theory. This stage, which follows the **Preoperational stage**, occurs between the ages of 7 and 11 years[8] and is characterized by the appropriate use of logic. Important processes during this stage are:

Seriation—the ability to sort objects in an order according to size, shape, or any other characteristic. For example, if given different-shaded objects they may make a color gradient.

Transitivity- The ability to recognize logical relationships among elements in a serial order, and perform 'transitive inferences' (for example, If A is taller than B, and B is taller than C, then A must be taller than C).

Classification—the ability to name and identify sets of objects according to appearance, size or other characteristic, including the idea that one set of objects can include another.

Decentering—where the child takes into account multiple aspects of a problem to solve it. For example, the child will no longer perceive an exceptionally wide but short cup to contain less than a normally-wide, taller cup.

Reversibility—the child understands that numbers or objects can be changed, then returned to their original state. For this reason, a child will be able to rapidly determine that if 4+4 equals t, t−4 will equal 4, the original quantity.

Conservation—understanding that quantity, length or number of items is unrelated to the arrangement or appearance of the object or items.

Elimination of Egocentrism—the ability to view things from another's perspective (even if they think incorrectly). For instance, show a child a comic in which Jane puts a doll under a box, leaves the room, and then Melissa moves the doll to a drawer, and Jane comes back. A child in the concrete operations stage will say that Jane will still think it's under the box even though the child knows it is in the drawer. (See also False-belief task).

Children in this stage can, however, only solve problems that apply to actual (concrete) objects or events, and not abstract concepts or hypothetical tasks.

Formal operational stage

The formal operational period is the fourth and final of the periods of cognitive development in Piaget's theory.[9] This stage, which follows the Concrete Operational stage, commences at around 11 years of age (puberty) and continues into adulthood.[9] In this stage, individuals move beyond concrete experiences and begin to think abstractly, reason logically and draw conclusions from the information available, as well as apply all these processes to hypothetical situations.[9] The abstract quality of the adolescent's thought at the formal operational level is evident in the adolescent's verbal problem solving ability.[9] The logical quality of the adolescent's thought is when children are more likely to solve problems in a trial-and-error fashion.[9] Adolescents begin to think more as a scientist thinks, devising plans to solve problems and systematically testing solutions.[9] They use hypothetical-deductive reasoning, which means that they develop hypotheses or best guesses, and systematically deduce, or conclude, which is the best path to follow in solving the problem.[9] During this stage the adolescent is able to understand such things as love, "shades of gray", logical proofs and values. During this stage the young person begins to entertain possibilities for the future and is fascinated with what they can be.[9] Adolescents are changing cognitively also by the way that they think about social matters.[9] Adolescent Egocentrism governs the way that adolescents think about social matters and is the heightened self-consciousness in them as they are which is reflected in their sense of personal uniqueness and invincibility.[9] Adolescent egocentrism can be dissected into two types of social thinking, imaginary audience that involves attention getting behavior, and personal fable which involves an adolescent's sense of personal uniqueness and invincibility.[9]

Challenges to Piagetian stage theory

Piagetians' accounts of development have been challenged on several grounds. First, as Piaget himself noted, development does not always progress in the smooth manner his theory seems to predict. 'Decalage', or unpredicted gaps in the developmental progression, suggest that the stage model is at best a useful approximation. More broadly, Piaget's theory is 'domain general', predicting that cognitive maturation occurs concurrently across different domains of knowledge (such as mathematics, logic, understanding of physics, of language, etc.). During the 1980s and 1990s, cognitive developmentalists were influenced by "neo-nativist" and evolutionary psychology ideas. These ideas de-emphasized domain general theories and emphasized domain specificity or modularity of mind. Modularity implies that different cognitive faculties may be largely independent of one another and thus develop according to quite different time-tables. In this vein, some cognitive developmentalists argued that rather than being domain general learners, children come equipped with domain specific theories, sometimes referred to as 'core knowledge', which allows them to break into learning within that domain. For example, even young infants appear to be sensitive to some predictable regularities in the movement and interactions of objects (e.g. that one object cannot pass through another), or in human behavior (e.g. that a hand repeatedly reaching for an object has that object, not just a particular path of motion, as its goal). These basic assumptions may be the building block out of which more elaborate knowledge is constructed. More recent work has strongly challenged some of the basic presumptions of the 'core knowledge' school, and revised ideas of domain generality—but from a newer dynamic systems approach, not from a revised Piagetian perspective. Dynamic systems approaches harken to modern neuroscientific research that was not available to Piaget when he was constructing his theory. One important finding is that domain-specific knowledge is constructed as children develop and integrate knowledge. This suggests more of a "smooth integration" of learning and development than either Piaget, or his neo-nativist critics, had envisioned. Additionally, some psychologists, such as Vygotsky and Jerome Bruner, thought differently from Piaget, suggesting that language was more important than Piaget implied.

Another recent challenge to Piaget's theory is a new theory called Ecological Systems Theory. This is based on the contextual influences in the child's life like his/her immediate family, school, society and the world, and how these impact the child's development.

The experience of Sudbury model schools shows that a great variety can be found in the minds of children, against Piaget's theory of universal steps in comprehension and general patterns in the acquisition of knowledge: "No two kids ever take the same path. Few are remotely similar. Each child is so unique, so exceptional" (Greenberg, 1987).[10]

Post Piagetian and Neo-Piagetian stages

In the recent years, several scholars attempted to ameliorate the problems of Piaget's theory by developing new theories and models that can accommodate evidence that violates Piagetian predictions and postulates. These models are summarized below.

- The neo-Piagetian theories of cognitive development, advanced by Case, Demetriou, Halford, Fischer, and Pascual-Leone, attempted to integrate Piaget´s theory with cognitive and differential theories of cognitive organization and development. Their aim was to better account for the cognitive factors of development and for intra-individual and inter-individual differences in cognitive development. They suggested that development along Piaget´s stages is due to increasing working memory capacity and processing efficiency. Moreover, Demetriou´s theory ascribes an important role to hypercognitive processes of self-recording, self-monitoring, and self-regulation and it recognizes the operation of several relatively autonomous domains of thought (Demetriou, 1998; Demetriou, Mouyi, Spanoudis, 2010).
- Postformal stages have been proposed. Kurt Fischer suggested two, Michael Commons presents evidence for four postformal stages: the systematic, metasystematic, paradigmatic and cross paradigmatic. (Commons & Richards,

2003; Oliver, 2004).

- A "sentential" stage has been proposed, said to occur before the early preoperational stage. Proposed by Fischer, Biggs and Biggs, Commons, and Richards.
- Searching for a micro-physiological basis for human mental capacity, Traill (1978, Section C5.4[11]; - 1999, Section 8.4[12]) proposed that there may be "pre-sensorimotor" stages ("$M^{-1}L$", "$M^{-2}L$", … …) — developed in the womb and/or transmitted genetically.

Postulated physical mechanisms underlying "schemes" and stages

Piaget himself (1967) considered the possibility of *RNA molecules* as likely embodiments of his still-abstract "schemes" (which he promoted as units of action) — though he did not come to any firm conclusion. At that time, due to work such as that of Holger Hydén, RNA concentrations had indeed been shown to correlate with learning, so the idea was quite plausible.

However, by the time of Piaget's death in 1980, this notion had lost favour. One main problem was over the protein which (it was assumed) such RNA would necessarily produce, and that did not fit in with observation. It then turned out, surprisingly, that only about 3% of RNA does code for protein (Mattick, 2001, 2003, 2004). Hence most of the remaining 97% (the "ncRNA") could now theoretically be available to serve as Piagetian schemes (or other regulatory roles now under investigation). The issue has not yet been resolved experimentally, but its theoretical aspects have been reviewed; (Traill 2005 / 2008).

Piagetian and post-Piagetian stage theories/heuristics

- Cheryl Armon's Stages of the Good Life
- Michael Barnes's stages of religious and scientific thinking
- Michael Lamport Commons' Model of Hierarchical Complexity
- Andreas Demetriou's Neo-Piagetian theories of cognitive development
- Kieran Egan's stages of understanding
- Suzy Gablik's stages of art history
- Christopher Hallpike's stages of moral understanding
- Lawrence Kohlberg's stages of moral development
- Don Lepan's theory of the origins of modern thought and drama
- Charles Radding's theory of the medieval intellectual development
- R.J. Robinson's stages of history and theory of the origins of intelligence
- Ashby, W.Ross (1952/1960) *Design for a Brain*. London: Chapman & Hall — gives a theoretical brain model which implies stages of development comparable to Piaget's; see Traill (1978).
- Stafford Beer, a cybernetician and business-consultant, attempted to apply Ashby's principles to Companies and Government organizations. (*e.g.* Beer, 1972).
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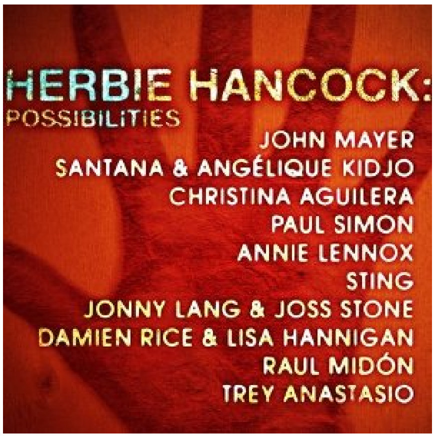
External links

- Piaget's Theory of Cognitive Development (http://www.edpsycinteractive.org/topics/cogsys/piaget.html)
- Cognitive development of a child (http://www.educationguideonline.net/cognitive-or-social-development-of-a-child/)
- Only one-third of adults can reason formally (http://www.brainstages.net/4thr.html)

Possibilities

Possibilities	



Studio album by Herbie Hancock	
Released	August 29, 2005 (UK) August 30, 2005 (U.S.)
Recorded	2005
Genre	Jazz
Label	Vector/Hear Music
Producer	Herbie Hancock, Jessica Hancock, John Alagía, Bob Brockman, Yaron Fuchs, Bryce Goggin, Steven "Steven J." Jordan, Rob Lucas, Alan Mintz, Greg Phillinganes, Paul Simon

Professional reviews

- *All About Jazz* (favorable) 2005 [1]
- Allmusic ★★★☆☆ 2005 [2]
- *The Independent* ★★☆☆☆ 2005 [3]
- LiveDaily (favorable) 2005 [4]
- *Mojo* ★★★☆☆ 2005 [5]
- PopMatters (mixed) 2005 [6]

Herbie Hancock chronology

Future2Future (2001)	***Possibilities*** (2005)	*River: The Joni Letters* (2007)

Possibilities is the forty-fifth studio album by American jazz musician Herbie Hancock, released in the United States on August 30, 2005 by Vector Recordings. The album features a variety of guest musicians such as John Mayer and Carlos Santana. It earned Hancock two nominations at the 2006 Grammy Awards: Best Pop Collaboration with Vocals for "A Song for You" (shared with pop singer Christina Aguilera) and Best Pop Instrumental Performance for "Gelo na Montanha" (shared with rock singer-guitarist Trey Anastasio). A motion picture entitled *Herbie Hancock: Possibilities*, released on DVD on April 18, 2006, depicts the recording of this album in many different discussions and performances with the collaborating artists.

Track listing

1. "Stitched Up" (featuring John Mayer) (Herbie Hancock, John Mayer) – 5:27
2. "Safiatou" (featuring Santana and Angélique Kidjo) (Harold Alexander) – 5:25
3. "A Song for You" (featuring Christina Aguilera) (Leon Russell) – 7:05
4. "I Do It for Your Love" (featuring Paul Simon) (Paul Simon) – 5:58
5. "Hush, Hush, Hush" (featuring Annie Lennox) (Paula Cole) – 4:46
6. "Sister Moon" (featuring Sting) (Sting) – 6:54
7. "When Love Comes to Town" (featuring Jonny Lang and Joss Stone) (Adam Clayton, David Evans, Larry Mullen, Jr., Paul Hewson) – 8:41
8. "Don't Explain" (featuring Damien Rice and Lisa Hannigan) (Arthur Herzog Jr., Billie Holiday) – 4:53
9. "I Just Called to Say I Love You" (featuring Raul Midón) (Stevie Wonder) – 5:27
10. "Gelo na Montanha" [1] (featuring Trey Anastasio) (Cyro Baptista, Herbie Hancock, Trey Anastasio) – 3:48

- [1] Portuguese for "Ice on the Mountain"

Charts

Chart (2005)[7] [8]	Peak position
Belgian Ultratop 50 Albums (Wallonia)	45
Dutch Albums Chart	33
Swiss Albums Chart	95
U.S. *Billboard* 200	22
U.S. *Billboard* Top Contemporary Jazz	1
U.S. *Billboard* Top Internet Albums	22

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[2] http://allmusic.com/cg/amg.dll?p=amg&sql=10:cu548qcxbtv4
[3] http://www.independent.co.uk/arts-entertainment/music/reviews/album-herbie-hancock--none-onestar-twostar-threestar-fourstar-fivestar-504238.html
[4] http://www.livedaily.com/news/Album_Review_Herbie_Hancock_Possibilities_Hear_MusicHancock_Music-8727.html?t=98
[5] http://www.tower.com/possibilities-herbie-hancock-cd/wapi/106104572
[6] http://www.popmatters.com/music/reviews/h/hancockherbie-possibilities.shtml
[7] "Possibilities > Charts & Awards > Billboard Albums" (http://allmusic.com/cg/amg.dll?p=amg&sql=10:anfpxqusld0e~T3). *Allmusic*. . Retrieved 2008-11-26.
[8] "Herbie Hancock – Possibilities – swisscharts.com" (http://swisscharts.com/showitem.asp?key=23025&cat=a). *SwissCharts.com*. . Retrieved 2008-11-26.

Prediction

A **prediction** or **forecast** is a statement about the way things will happen in the future, often but not always based on experience or knowledge. While there is much overlap between *prediction* and *forecast*, a *prediction* may be a statement that some outcome is expected, while a *forecast* may cover a range of possible outcomes.

Although guaranteed information about the information is in many cases impossible, prediction is necessary to allow plans to be made about possible developments; Howard H. Stevenson writes that prediction in business "... is at least two things: Important and hard."[1]

Prediction is closely related to uncertainty. Reference class forecasting was developed to eliminate or reduce uncertainty in prediction.[2]

The etymology of *prediction* is Latin (*præ-*, "before," and *dicere*, "to say").

Informal prediction from hypothesis

The Old Farmer's Almanac is famous in the US for its (not necessarily accurate) long-range weather predictions.

Outside the rigorous context of science, prediction is often confused with informed guess or opinion.

A prediction of this kind might be (inductively) valid if the predictor is a knowledgeable person in the field and is employing sound reasoning and accurate data. Large corporations invest heavily in this kind of activity to help focus attention on possible events, risks and business opportunities, using futurists. Such work brings together all available past and current data, as a basis to develop reasonable expectations about the future.

Opinion polls

In politics it is common to attempt to predict the outcome of elections via political forecasting techniques (or assess the popularity of politicians) through the use of opinion polls. Prediction games have been used by many corporations and governments to learn about the most likely outcome of future events.

Statistics

In statistics, prediction is a part of statistical inference, and the field is known as predictive inference.

Supernatural (prophecy)

Predictions have often been made, from antiquity until the present, by using paranormal or supernatural means such as prophecy or by observing omens. Methods including water divining, astrology, numerology, fortune telling, interpretation of dreams, and many other forms of divination, have been used for millennia to attempt to predict the future. These means of prediction have not been substantiated by controlled experiments, and are disputed by most, including scientists and skeptics.

Prediction in science

In science a prediction is a rigorous, often quantitative, statement, forecasting what will happen under specific conditions; for example, if an apple falls from a tree it will be attracted towards the center of the earth by gravity with a specified and constant acceleration. The scientific method is built on testing assertions that are logical consequences of scientific theories. This is done through repeatable experiments or observational studies.

A scientific theory whose assertions are contradicted by observations and evidence will be rejected. Notions that make no *testable* predictions are usually considered not to be part of science (protoscience or nescience) until testable predictions can be made.

New theories that generate many new predictions can more easily be supported or falsified (see predictive power).

In some cases the probability of an outcome, rather than a specific outcome, can be predicted, for example in much of quantum physics.

Mathematical equations and models, and computer models, are frequently used to describe the past and future behaviour of something.

In microprocessors, branch prediction permits avoidance of pipeline emptying at branch instructions. In engineering, possible failure modes are predicted and avoided by correcting the mechanism causing the failure.

Accurate prediction and forecasting are very difficult in some areas, such as software reliability, natural disasters, pandemics, demography, population dynamics and meteorology.

Scientific hypothesis and prediction

Established science makes useful predictions which are considered to be extremely reliable and accurate; for example, eclipses are routinely predicted.

New theories make predictions which allow them to be falsified if the predictions are not borne out. For example in the early twentieth century the scientific consensus was that there was an absolute frame of reference, given the name *luminiferous ether*. The famous Michelson-Morley experiment ruled this out, falsifying the idea of an absolute frame and leaving the very counter-intuitive special theory of relativity as the only possibility.

Albert Einstein's theory of general relativity could not easily be tested as it did not produce any effects observable on a terrestrial scale. However, the theory predicted that large masses such as stars would bend light, in contradiction to accepted theory; this was observed in a 1919 eclipse.

Finance

Mathematical models of stock market behaviour are also unreliable in predicting future behaviour. Consequently, stock investors may anticipate or predict a stock market boom, or fail to anticipate or predict a stock market crash.

Some correlation has been seen between actual stock market movements and prediction data from large groups in surveys and prediction games.

An actuary uses actuarial science to assess and predict future business risk, such that the risk(s) can be mitigated.

For example, in insurance an actuary would use a life table to predict (truly, estimate or compute) life expectancy.

Vision and prophecy

In literature, vision and prophecy are literary devices used to present a possible timeline of future events. They can be distinguished by vision referring to what an individual sees happen. The New Testament book of Revelation (Bible) thus uses vision as a literary device in this regard. It is also prophecy or prophetic literature when it is related by an individual in a sermon or other public forum.

Prediction in fiction

Fiction (especially fantasy, forecasting and science fiction) often features instances of prediction achieved by unconventional means.

- In fantasy literature, predictions are often obtained through magic or prophecy, sometimes referring back to old traditions. For example, in J. R. R. Tolkien's *The Lord of the Rings*, many of the characters possess an awareness of events extending into the future, sometimes as prophecies, sometimes as more-or-less vague 'feelings'. The character Galadriel, in addition, employs a water "mirror" to show images, sometimes of possible future events.
- In some of Philip K. Dick's stories, mutant humans called *precogs* can foresee the future (ranging from days to years). In the story called *The Golden Man*, an exceptional mutant can predict the future to an indefinite range (presumably up to his death), and thus becomes completely non-human, an animal that follows the predicted paths automatically. Precogs also play an essential role in another of Dick's stories, *The Minority Report*, which was turned into a film by Steven Spielberg in 2002.
- In the *Foundation* series by Isaac Asimov, a mathematician finds out that historical events (up to some detail) can be theoretically modelled using equations, and then spends years trying to put the theory in practice. The new science of psychohistory founded upon his success can simulate history and extrapolate the present into the future.
- In Frank Herbert's sequels to Dune, his characters are dealing with the repercussions of being able to see the possible futures and select amongst them. Herbert sees this as a trap of stagnation, and his characters follow a Golden Path out of the trap.
- In Ursula K. Le Guin's *The Left Hand of Darkness*, the humanoid inhabitants of planet Gethen have mastered the art of prophecy and routinely produce data on past, present or future events on request. In this story, this was a minor plot device.

See also

- Astrology
- Famous predictions
- Futures Studies
- Optimism bias
- Predictions of Soviet collapse
- prediction games
- Prediction interval
- Prediction market
- Predictive medicine
- Reference class forecasting
- Regression analysis
- Thought experiment
- Traffic forecasting
- Trend estimation
- Weather forecasting
- Delphi method

- Forecasting
- Egain Forecasting

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External links

- Predictions (http://www.dmoz.org/Society/Future/Predictions/) at the Open Directory Project

Premise

In logic, an argument is a set of one or more declarative sentences (or "propositions") known as the **premises** along with another declarative sentence (or "proposition") known as the conclusion. Aristotle held that any logical argument could be reduced to two premises and a conclusion.[1] Premises are sometimes left unstated in which case they are called missing premises, for example:

> Socrates is mortal, since all men are mortal.

It is evident that a tacitly understood claim is that Socrates is a man. The fully expressed reasoning is thus:

> Since all men are mortal and Socrates is a man, it follows that Socrates is mortal.

In this example, the first two independent clauses preceding the comma (namely, "all men are mortal" and "Socrates is a man") are the premises, while "Socrates is mortal" is the conclusion.

The proof of a conclusion depends on both the truth of the premises and the validity of the argument.

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Principle

A **principle** is a law or rule that has to be, or usually is to be followed, or can be desirably followed, or is an inevitable consequence of something, such as the laws of nature or the way that a device is constructed.

Examples of principles:

- a descriptive comprehensive and fundamental law, doctrine, or assumption
- a normative rule or code of conduct,
- a law or fact of nature underlying the working of an artificial device.

Principle as cause

The principle of any effect is the cause that produces it!

Depending on the way the cause is understood the basic law governing that cause may acquire some distinction in its expression.

Principle of Causality, as efficient cause

The efficient cause is the one that produces the necessary effect, as long as the necessary and sufficient conditions are provided.

The scientific process generally consists of establishing a cause by analyzing its effect upon objects. In this way, a description can be established to explain what principle brought about the change-effect. For this reason the principle of cause is considered to be a determining factor in the production of facts.

With the belief that "every effect has a cause", it's considered that everything that begins to exist must have a cause. This is considered as the principle of causality. It was formulated by Aristotle as "Everything that moves is moved by another". This principle is used as a powerful argument for the *potential existence* of a creator-god dues to the regressive nature of the principle, which inevitably requires a first-cause.

Principle as a final cause

Final cause is the end, or goal, which guides one to take the necessary actions to obtain it.

For that there needs to be an intelligence capable of conceiving the end and realizing that certain actions must be taken to achieve the goal.

Science does not recognize the finality of the natural causes as a guiding principle of investigation.

It is also understood therefore that the principle guides the action as a norm or rule of behavior, which produces two types of principles.

Principle as law

Principle as scientific law

Laws Physics. Laws Statistics. Laws Biological. Laws of nature are those that can not be proven explicitly, however we can measure and quantify them observing the results that they produce. (Vague or unclear statement).

Principle as moral law

It represents a set of values that orientate and rule the conduct of a concrete society. The law establishes an obligation in the individual's conscience that belongs to the cultural field in which such values are accepted. It supposes the liberty of the individual as cause, that acts without external coercion, through a process of socialization.

Principle as a juridic law

It represents a set of values that inspire the written norms that organize the life of a society submitting to the powers of an authority, generally the State. The law establishes a legal obligation, in a coercive way; it therefore acts as principle conditioning of the action that limits the liberty of the individuals.

Principle as axiom or logical fundament

Principle of Sufficient Reason

This is based on the truth or intelligibility of the being. The being has an identity and is intelligible, in virtue that it is. (The intelligibility is the identity of the being with intelligence.) That in virtue of which the being is intelligible, is called the reason or fundament of being. Here is the ontological principle: ‘’Every being has enough reason’’. Without this enough reason, the identity with oneself would be lost, becoming a non-being and therefore nothing. If a being lacked enough reason, of explication, it wouldn't be intelligible, conceiving itself as an absurd unreal non-being.

Principle of Identity

This comes in consequence from the characteristic of identity of the being. The being is the being, and whoever denies that statement would be against the previously exposed. However, saying "what is, is what is" would seem, as a trial, merely analytical (A = A), but one realizes that in every sentence there is a direct relation between the predicate and the subject. To say "the earth is round", corresponds to a direct relation between the subject and the predicate. Taking this to the sentence "the being is the being", we realize the principle of identity that the being possesses.

Principle of contradiction

"One thing can't be and not be at the same time, under the same aspect." Example: It is not possible that in exactly the same moment it rains and doesn't rain (in the same place). see Law of noncontradiction

Principle of excluded middle

The principle of the excluding third or "principium tertium exclusum" is a principle of the traditional logic formulated canonically by Leibniz as: either A is B or A isn't B. It is read the following way: either P is true, or its denial ¬P is. It is also known as "*tertium non datur*" ('A third (thing) is not). Classically it is considered to be one of the most important fundamental principles or laws of thought (along with the principles of identity, no contradiction and sufficient reason). see Law of excluded middle.

See also

- Axiom
- Corollary
- Deduction
- Law of excluded middle
- Law of noncontradiction
- Logical consequence

Probability

Probability is a way of expressing knowledge or belief that an event will occur or has occurred. The concept has been given an exact mathematical meaning in probability theory, which is used extensively in such areas of study as mathematics, statistics, finance, gambling, science, and philosophy to draw conclusions about the likelihood of potential events and the underlying mechanics of complex systems.

Interpretations

The word *probability* does not have a consistent direct definition. In fact, there are two broad categories of **probability interpretations**, whose adherents possess different (and sometimes conflicting) views about the fundamental nature of probability:

1. Frequentists talk about probabilities only when dealing with experiments that are random and well-defined. The probability of a random event denotes the *relative frequency of occurrence* of an experiment's outcome, when repeating the experiment. Frequentists consider probability to be the relative frequency "in the long run" of outcomes.[1]
2. Bayesians, however, assign probabilities to any statement whatsoever, even when no random process is involved. Probability, for a Bayesian, is a way to represent an individual's *degree of belief* in a statement, or an objective degree of rational belief, given the evidence.

Etymology

The word *Probability* derives from latin word *probabilitas* that can also mean *probity*, a measure of the authority of a witness in a legal case in Europe, and often correlated with the witness's nobility. In a sense, this differs much from the modern meaning of *probability*, which, in contrast, is used as a measure of the weight of empirical evidence, and is arrived at from inductive reasoning and statistical inference.[2] [3]

History

The scientific study of probability is a modern development. Gambling shows that there has been an interest in quantifying the ideas of probability for millennia, but exact mathematical descriptions of use in those problems only arose much later.

According to Richard Jeffrey, "Before the middle of the seventeenth century, the term 'probable' (Latin *probabilis*) meant *approvable*, and was applied in that sense, univocally, to opinion and to action. A probable action or opinion was one such as sensible people would undertake or hold, in the circumstances."[4] However, in legal contexts especially, 'probable' could also apply to propositions for which there was good evidence.[5]

Aside from some elementary considerations made by Girolamo Cardano in the 16th century, the doctrine of probabilities dates to the correspondence of Pierre de Fermat and Blaise Pascal (1654). Christiaan Huygens (1657) gave the earliest known scientific treatment of the subject. Jakob Bernoulli's *Ars Conjectandi* (posthumous, 1713) and Abraham de Moivre's *Doctrine of Chances* (1718) treated the subject as a branch of mathematics. See Ian Hacking's *The Emergence of Probability* and James Franklin's *The Science of Conjecture* for histories of the early development of the very concept of mathematical probability.

The theory of errors may be traced back to Roger Cotes's *Opera Miscellanea* (posthumous, 1722), but a memoir prepared by Thomas Simpson in 1755 (printed 1756) first applied the theory to the discussion of errors of observation. The reprint (1757) of this memoir lays down the axioms that positive and negative errors are equally probable, and that there are certain assignable limits within which all errors may be supposed to fall; continuous errors are discussed and a probability curve is given.

Pierre-Simon Laplace (1774) made the first attempt to deduce a rule for the combination of observations from the principles of the theory of probabilities. He represented the law of probability of errors by a curve $y = \phi(x)$, x being any error and y its probability, and laid down three properties of this curve:

1. it is symmetric as to the y-axis;
2. the x-axis is an asymptote, the probability of the error ∞ being 0;
3. the area enclosed is 1, it being certain that an error exists.

He also gave (1781) a formula for the law of facility of error (a term due to Lagrange, 1774), but one which led to unmanageable equations. Daniel Bernoulli (1778) introduced the principle of the maximum product of the probabilities of a system of concurrent errors.

The method of least squares is due to Adrien-Marie Legendre (1805), who introduced it in his *Nouvelles méthodes pour la détermination des orbites des comètes* (*New Methods for Determining the Orbits of Comets*). In ignorance of Legendre's contribution, an Irish-American writer, Robert Adrain, editor of "The Analyst" (1808), first deduced the law of facility of error,

$$\phi(x) = ce^{-h^2x^2},$$

h being a constant depending on precision of observation, and c a scale factor ensuring that the area under the curve equals 1. He gave two proofs, the second being essentially the same as John Herschel's (1850). Gauss gave the first proof which seems to have been known in Europe (the third after Adrain's) in 1809. Further proofs were given by Laplace (1810, 1812), Gauss (1823), James Ivory (1825, 1826), Hagen (1837), Friedrich Bessel (1838), W. F. Donkin (1844, 1856), and Morgan Crofton (1870). Other contributors were Ellis (1844), De Morgan (1864), Glaisher (1872), and Giovanni Schiaparelli (1875). Peters's (1856) formula for r, the probable error of a single observation, is well known.

In the nineteenth century authors on the general theory included Laplace, Sylvestre Lacroix (1816), Littrow (1833), Adolphe Quetelet (1853), Richard Dedekind (1860), Helmert (1872), Hermann Laurent (1873), Liagre, Didion, and Karl Pearson. Augustus De Morgan and George Boole improved the exposition of the theory.

Andrey Markov introduced the notion of Markov chains (1906) playing an important role in theory of stochastic processes and its applications.

The modern theory of probability based on the measure theory was developed by Andrey Kolmogorov (1931).

On the geometric side (see integral geometry) contributors to *The Educational Times* were influential (Miller, Crofton, McColl, Wolstenholme, Watson, and Artemas Martin).

Mathematical treatment

In mathematics, a probability of an event *A* is represented by a real number in the range from 0 to 1 and written as P(*A*), p(*A*) or Pr(*A*).[6] An impossible event has a probability of 0, and a certain event has a probability of 1. However, the converses are not always true: probability 0 events are not always impossible, nor probability 1 events certain. The rather subtle distinction between "certain" and "probability 1" is treated at greater length in the article on "almost surely".

The *opposite* or *complement* of an event *A* is the event [not *A*] (that is, the event of *A* not occurring); its probability is given by P(not *A*) = 1 - P(*A*).[7] As an example, the chance of not rolling a six on a six-sided die is 1 − (chance of rolling a six) $= 1 - \frac{1}{6} = \frac{5}{6}$. See Complementary event for a more complete treatment.

If both the events *A* and *B* occur on a single performance of an experiment this is called the intersection or joint probability of *A* and *B*, denoted as $P(A \cap B)$. If two events, *A* and *B* are independent then the joint probability is

$$P(A \text{ and } B) = P(A \cap B) = P(A)P(B),$$

for example, if two coins are flipped the chance of both being heads is $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$.[8]

If either event *A* or event *B* or both events occur on a single performance of an experiment this is called the union of the events *A* and *B* denoted as $P(A \cup B)$. If two events are mutually exclusive then the probability of either occurring is

$$P(A \text{ or } B) = P(A \cup B) = P(A) + P(B).$$

For example, the chance of rolling a 1 or 2 on a six-sided die is $P(1 \text{ or } 2) = P(1) + P(2) = \frac{1}{6} + \frac{1}{6} = \frac{1}{3}$.
If the events are not mutually exclusive then

$$\mathrm{P}\left(A \text{ or } B\right) = \mathrm{P}\left(A\right) + \mathrm{P}\left(B\right) - \mathrm{P}\left(A \text{ and } B\right).$$

For example, when drawing a single card at random from a regular deck of cards, the chance of getting a heart or a face card (J,Q,K) (or one that is both) is $\frac{13}{52} + \frac{12}{52} - \frac{3}{52} = \frac{11}{26}$, because of the 52 cards of a deck 13 are hearts, 12 are face cards, and 3 are both: here the possibilities included in the "3 that are both" are included in each of the "13 hearts" and the "12 face cards" but should only be counted once.

Conditional probability is the probability of some event *A*, given the occurrence of some other event *B*. Conditional probability is written *P*(*A*|*B*), and is read "the probability of *A*, given *B*". It is defined by

$$P(A \mid B) = \frac{P(A \cap B)}{P(B)}.$$ [9]

If $P(B) = 0$ then $P(A \mid B)$ is undefined.

Summary of probabilities

Event	Probability
A	$P(A) \in [0,1]$
not A	$P(A') = 1 - P(A)$
A or B	
A and B	$P(A \cap B) = P(A\|B)P(B)$ $= P(A)P(B) \quad$ if A and B are independent
A given B	$P(A \mid B) = \frac{P(A \cap B)}{P(B)}$

Theory

Like other theories, the theory of probability is a representation of probabilistic concepts in formal terms—that is, in terms that can be considered separately from their meaning. These formal terms are manipulated by the rules of mathematics and logic, and any results are then interpreted or translated back into the problem domain.

There have been at least two successful attempts to formalize probability, namely the Kolmogorov formulation and the Cox formulation. In Kolmogorov's formulation (see probability space), sets are interpreted as events and probability itself as a measure on a class of sets. In Cox's theorem, probability is taken as a primitive (that is, not further analyzed) and the emphasis is on constructing a consistent assignment of probability values to propositions. In both cases, the laws of probability are the same, except for technical details.

There are other methods for quantifying uncertainty, such as the Dempster-Shafer theory or possibility theory, but those are essentially different and not compatible with the laws of probability as they are usually understood.

Applications

Two major applications of probability theory in everyday life are in risk assessment and in trade on commodity markets. Governments typically apply probabilistic methods in environmental regulation where it is called "pathway analysis", often measuring well-being using methods that are stochastic in nature, and choosing projects to undertake based on statistical analyses of their probable effect on the population as a whole.

A good example is the effect of the perceived probability of any widespread Middle East conflict on oil prices - which have ripple effects in the economy as a whole. An assessment by a commodity trader that a war is more likely vs. less likely sends prices up or down, and signals other traders of that opinion. Accordingly, the probabilities are not assessed independently nor necessarily very rationally. The theory of behavioral finance emerged to describe the effect of such groupthink on pricing, on policy, and on peace and conflict.

It can reasonably be said that the discovery of rigorous methods to assess and combine probability assessments has had a profound effect on modern society. Accordingly, it may be of some importance to most citizens to understand how odds and probability assessments are made, and how they contribute to reputations and to decisions, especially in a democracy.

Another significant application of probability theory in everyday life is reliability. Many consumer products, such as automobiles and consumer electronics, utilize reliability theory in the design of the product in order to reduce the probability of failure. The probability of failure may be closely associated with the product's warranty.

Relation to randomness

In a deterministic universe, based on Newtonian concepts, there is no probability if all conditions are known. In the case of a roulette wheel, if the force of the hand and the period of that force are known, then the number on which the ball will stop would be a certainty. Of course, this also assumes knowledge of inertia and friction of the wheel, weight, smoothness and roundness of the ball, variations in hand speed during the turning and so forth. A probabilistic description can thus be more useful than Newtonian mechanics for analyzing the pattern of outcomes of repeated rolls of roulette wheel. Physicists face the same situation in kinetic theory of gases, where the system, while deterministic *in principle*, is so complex (with the number of molecules typically the order of magnitude of Avogadro constant $6.02 \cdot 10^{23}$) that only statistical description of its properties is feasible.

A revolutionary discovery of 20th century physics was the random character of all physical processes that occur at sub-atomic scales and are governed by the laws of quantum mechanics. The wave function itself evolves deterministically as long as no observation is made, but, according to the prevailing Copenhagen interpretation, the randomness caused by the wave function collapsing when an observation is made, is fundamental. This means that probability theory is required to describe nature. Others never came to terms with the loss of determinism. Albert Einstein famously remarked in a letter to Max Born: *Jedenfalls bin ich überzeugt, daß der Alte nicht würfelt.* (*I am convinced that God does not play dice*). Although alternative viewpoints exist, such as that of quantum decoherence being the cause of an *apparent* random collapse, at present there is a firm consensus among physicists that probability theory is necessary to describe quantum phenomena.

See also

- Black Swan theory
- Calculus of predispositions
- Chance (disambiguation)
- Class membership probabilities
- Decision theory
- Equiprobable
- Fuzzy measure theory
- Game theory
- Gaming mathematics
- Information theory
- Important publications in probability
- Measure theory
- Negative probability
- Probabilistic argumentation
- Probabilistic logic
- Random fields
- Random variable
- List of scientific journals in probability
- List of statistical topics
- Stochastic process
- Wiener process

Notes

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[6] Olofsson, Peter. (2005) Page 8.

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Quotations

- Damon Runyon, "It may be that the race is not always to the swift, nor the battle to the strong - but that is the way to bet."
- Pierre-Simon Laplace "It is remarkable that a science which began with the consideration of games of chance should have become the most important object of human knowledge." *Théorie Analytique des Probabilités*, 1812.
- Richard von Mises "The unlimited extension of the validity of the exact sciences was a characteristic feature of the exaggerated rationalism of the eighteenth century" (in reference to Laplace). *Probability, Statistics, and Truth,* p 9. Dover edition, 1981 (republication of second English edition, 1957).

External links

- Probability and Statistics EBook (http://wiki.stat.ucla.edu/socr/index.php/EBook)
- Edwin Thompson Jaynes. *Probability Theory: The Logic of Science*. Preprint: Washington University, (1996). — HTML index with links to PostScript files (http://omega.albany.edu:8008/JaynesBook.html) and PDF (http://bayes.wustl.edu/etj/prob/book.pdf) (first three chapters)
- People from the History of Probability and Statistics (Univ. of Southampton) (http://www.economics.soton.ac.uk/staff/aldrich/Figures.htm)
- Probability and Statistics on the Earliest Uses Pages (Univ. of Southampton) (http://www.economics.soton.ac.uk/staff/aldrich/Probability Earliest Uses.htm)
- Earliest Uses of Symbols in Probability and Statistics (http://jeff560.tripod.com/stat.html) on Earliest Uses of Various Mathematical Symbols (http://jeff560.tripod.com/mathsym.html)
- A tutorial on probability and Bayes' theorem devised for first-year Oxford University students (http://www.celiagreen.com/charlesmccreery/statistics/bayestutorial.pdf)
- pdf file of An Anthology of Chance Operations (1963) (http://ubu.com/historical/young/index.html) at UbuWeb
- Probability Theory Guide for Non-Mathematicians (http://probability.infarom.ro)
- Understanding Risk and Probability (http://www.bbc.co.uk/raw/money/express_unit_risk/) with BBC raw
- Introduction to Probability - eBook (http://www.dartmouth.edu/~chance/teaching_aids/books_articles/probability_book/book.html), by Charles Grinstead, Laurie Snell Source (http://bitbucket.org/shabbychef/numas_text/) *(GNU Free Documentation License)*

Proposition

In logic and philosophy, the term **proposition** (from the word "proposal") refers to both (a) the *"content"* or *"meaning"* of a meaningful declarative sentence or (b) the pattern of symbols, marks, or sounds that make up a meaningful declarative sentence. The meaning of a proposition includes that it has the quality or property of being either true or false, and as such propositions are called truthbearers.

The existence of propositions in the abstract sense, as well as the existence of "meanings", is disputed by some philosophers. Where the concept of a "meaning" is admitted, its nature is controversial. In earlier texts writers have not always made it sufficiently clear whether they are using the term *proposition* in sense of the words or the "meaning" expressed by the words.[1] To avoid the controversies and ontological implications, the term *sentence* is often now used instead of *proposition* to refer to just those strings of symbols that are truthbearers, being either true or false under an interpretation. Strawson advocated the use of the term "statement", and this is the current usage in mathematical logic.

Historical usage

Usage in Aristotle

Aristotelian logic identifies a proposition as a sentence which affirms or denies a predicate of a subject. An Aristotelian proposition may take the form "All men are mortal" or "Socrates is a man." In the first example the subject is "men" and the predicate "are mortal". In the second example the subject is "Socrates" and the predicate is "is a man".

Usage by the logical positivists

Often propositions are related to closed sentences to distinguish them from what is expressed by an open sentence. In this sense, propositions are "statements" that are truth bearers. This conception of a proposition was supported by the philosophical school of logical positivism.

Some philosophers argue that some (or all) kinds of speech or actions besides the declarative ones also have propositional content. For example, yes-no questions present propositions, being inquiries into the truth value of them. On the other hand, some signs can be declarative assertions of propositions without forming a sentence nor even being linguistic, e.g. traffic signs convey definite meaning which is either true or false.

Propositions are also spoken of as the content of beliefs and similar intentional attitudes such as desires, preferences, and hopes. For example, "I desire *that I have a new car*," or "I wonder *whether it will snow*" (or, whether it is the case that "it will snow"). Desire, belief, and so on, are thus called propositional attitudes when they take this sort of content.

Usage by Russell

Bertrand Russell held that propositions were structured entities with objects and properties as constituents. Others have held that a proposition is the set of possible worlds/states of affairs in which it is true. One important difference between these views is that on the Russellian account, two propositions that are true in all the same states of affairs can still be differentiated. For instance, the proposition that two plus two equals four is distinct on a Russellian account from three plus three equals six. If propositions are sets of possible worlds, however, then all mathematical truths are the same set (the set of all possible worlds).

Relation to the mind

In relation to the mind, propositions are discussed primarily as they fit into propositional attitudes. Propositional attitudes are simply attitudes characteristic of folk psychology (belief, desire, etc.) that one can take toward a proposition (e.g. 'it is raining', 'snow is white', etc.). In English, propositions usually follow folk psychological attitudes by a "that clause" (e.g. "Jane believes *that* it is raining"). In philosophy of mind and psychology, mental states are often taken to primarily consist in propositional attitudes. The propositions are usually said to be the "mental content" of the attitude. For example, if Jane has a mental state of believing that it is raining, her mental content is the proposition 'it is raining'. Furthermore, since such mental states are *about* something (namely propositions), they are said to be intentional mental states. Philosophical debates surrounding propositions as they relate to propositional attitudes have also recently centered on whether they are internal or external to the agent or whether they are mind-dependent or mind-independent entities (see the entry on internalism and externalism in philosophy of mind).

Treatment in logic

As noted above, in Aristotelian logic a proposition is a particular kind of sentence, one which affirms or denies a predicate of a subject. Aristotelian propositions take forms like "All men are mortal" and "Socrates is a man."

In mathematical logic, propositions, also called "propositional formulas" or "statement forms", are statements that do not contain quantifiers. They are composed of well-formed formulas consisting entirely of atomic formulas, the five logical connectives, and symbols of grouping (parentheses etc.). Propositional logic is one of the few areas of mathematics that is totally solved, in the sense that it has been proven internally consistent, every theorem is true, and every true statement can be proved.[2] (From this fact, and Gödel's Theorem, it is easy to see that propositional logic is not sufficient to construct the set of integers.) The most common extension of propositional logic is called predicate logic, which adds variables and quantifiers.

Objections to propositions

Attempts to provide a workable definition of proposition include

> Two meaningful declarative sentences express the same proposition if and only if they mean the same thing.

thus defining *proposition* in terms of synonymity. For example, "Snow is white" (in English) and "Schnee ist weiß" (in German) are different sentences, but they say the same thing, so they express the same proposition.

> Two meaningful declarative sentence-tokens express the same proposition if and only if they mean the same thing.

Unfortunately, the above definition has the result that two sentences/sentence-tokens which have the same meaning and thus express the same proposition, could have different truth-values, e.g. "I am Spartacus" said by Spartacus and said by John Smith; and e.g. "It is Wednesday" said on a Wednesday and on a Thursday.

In mathematical logic, this problem is solved with quantifiers. Both sentences are predicates, not propositions, because "I" and "It" are variables, and predicates only have a truth value when they are quantified. "For all days, it is Wednesday." is false. "There exist a day, such that it is Wednesday." is true.[3]

A number of philosophers and linguists claim that all definitions of a proposition are too vague to be useful. For them, it is just a misleading concept that should be removed from philosophy and semantics. W.V. Quine maintained that the indeterminacy of translation prevented any meaningful discussion of propositions, and that they should be discarded in favor of sentences.[4] Strawson advocated the use of the term "statement".

Related concepts

Facts are verifiable information.[5] Simple facts are often stated as propositions: "Apples are a type of fruit." The opposite statement—"Apples are not a type of fruit"—is still a properly formulated proposition, even though it is false (not a fact). Most statements of fact are compound facts: e.g., that apples exist, that fruit exists, that there are multiple types of fruit, etc.

A premise is a proposition that is used as the foundation for drawing conclusions. For example:

- *Premise*: "Apples are a type of fruit."
- *Premise*: "All types of fruit are food."
- *Conclusion*: "Therefore, apples are food."

If the conclusion is false then either one or more of the premisses is false or the process of combining the premises is logically invalid. If the premisses are true and the process is logically valid, then the conclusion must be true.

See also

- Main contention

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External links

- Stanford Encyclopedia of Philosophy articles on:
  - Propositions (http://plato.stanford.edu/entries/propositions/), by Matthew McGrath
  - Singular Propositions (http://plato.stanford.edu/entries/propositions-singular/), by Greg Fitch
  - Structured Propositions (http://plato.stanford.edu/entries/propositions-structured/), by Jeffrey C. King

Psychology of reasoning

The **psychology of reasoning** is the study of how people reason, often broadly defined as the process of drawing conclusions to inform how people solve problems and make decisions.[1] It is at the intersection of psychology, philosophy, linguistics, cognitive science, artificial intelligence, logic, and probability theory.

Overview

Psychological experiments on how humans and other animals reason have been carried out for over 100 years. An enduring question is whether or not people have the capacity to be rational. What does it mean to be rational? Current research in this area addresses various questions about reasoning, rationality, intelligence, relationships between emotion and reasoning, and development.

Everyday reasoning

How do people reason about sentences in natural language? Most experimentation on deduction has been carried out on hypothetical thought, in particular, examining how people reason about conditionals, e.g., *If A then B* [2] . Participants in experiments make the modus ponens inference, given the indicative conditional *If A then B*, and given the premise *A*, they conclude *B*. But given the indicative conditional and the minor premise for the modus tollens inference, *not-B*, about half of the participants in experiments conclude *not-A* and the remainder conclude that nothing follows.[3] .

The ease with which people make conditional inferences is affected by content, as demonstrated in the well-known selection task developed by Peter Wason. Participants are better able to test a conditional that contains sensible content, e.g., *if the envelope is sealed then it must have a 50 cent stamp on it* compared to one that contains symbolic content, e.g., *if the letter is a vowel then the number is even* [4] . Background knowledge can also lead to the suppression of even the simple modus ponens inference [5] Participants given the conditional *if Lisa has an essay to write then she studies late in the library* and the premise *Lisa has an essay to write* make the modus ponens inference 'she studies late in the library', but the inference is suppressed when they are also given a second conditional *if it the library stays open then she studies late in the library*. Interpretations of the suppression effect are controversial [6] [7]

Other investigations of propositional inference examine how people think about disjunctive alternatives, e.g., *A or else B*, and how they reason about negation, e.g., *It is not the case that A and B*. Many experiments have been carried out to examine how people make relational inferences, including comparisons, e.g., *A is better than B*. Such investigations also concern spatial inferences, e.g. *A is in front of B* and temporal inferences, e.g. *A occurs before B* [8] . Other common tasks include categorical syllogisms, used to examine how people reason about quantifiers such as *All* or *Some*, e.g., *Some of the A are not B*. [9] .

Theories of reasoning

There are several alternative theories of the cognitive processes that human reasoning is based on [10] . One view is that people rely on a mental logic consisting of formal (abstract or syntactic) inference rules similar to those developed by logicians in the propositional calculus [11] . Another view is that people rely on domain-specific or content-sensitive rules of inference[12] . A third view is that people rely on mental models, that is, mental representations that correspond to imagined possibilities [13] . A fourth view is that people compute probabilities [14] .

One controversial theoretical issue is the identification of an appropriate competence model, or a standard against which to compare human reasoning. Initially classical logic was chosen as a competence model.[15] Subsequently some researchers opted for non-monotonic logic[16] [17] and Bayesian probability.[18] Research on mental models and reasoning has led to the suggestion that people are rational in principle but err in practice [19] [20] . Connectionist approaches towards reasoning have also been proposed.[21]

Development of reasoning

How does reasoning develop? Jean Piaget's theory of cognitive development[22] describes a sequence of stages in the development of reasoning from infancy to adulthood. According to the neo-Piagetian theories of cognitive development, changes in reasoning with development come from increasing working memory capacity, increasing speed of processing, and enhanced executive functions and control. Increasing self-awareness is also an important factor.[23]

Reasoning and intelligence

How does reasoning relate to intelligence?[24]

Different sorts of reasoning

Psychologically, what are the relationships between induction, deduction, abduction, and analogy?

Pragmatics and reasoning

- How do various related factors such as linguistic pragmatics and emotion relate to the inferences people draw?[25][26]

Neuroscience of reasoning

- What are the neural correlates of reasoning, often investigated using event-related potentials and functional magnetic resonance imaging?[27]

External links

- London Reasoning Workshop [28]
- Logic in the Humanities, Social and Computational sciences (LogICCC) [29]

Notes

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Reason

Reason is a mental faculty (or ability) found in humans, that is able to generate conclusions from assumptions or premises. In other words, it is amongst other things the means by which rational beings propose specific **reasons**, or explanations of cause and effect. In contrast to reason as an abstract noun, *a reason* is a consideration which explains or justifies.[1]

The Sleep of Reason Produces Monsters (etching by Goya, c. 1799)

Reason is particularly associated with human nature, that which is unique and definitive about being human. As a way of coming to conclusions, it is often contrasted not only with the ways in which non-human animals appear to make decisions, but also with decisions based upon authority, intuition, emotion, mysticism, superstition, and faith. Reason is thought by rationalists to be more reliable in discovering what is true or what is best. The precise way in which reason differs from emotion, faith, and tradition is controversial, because all three are considered to be both potentially rational, and potentially in conflict with reason.

The essential difference between reason and other modes of consciousness is in explanation: thinking is more reasoned or rational if it is more consciously thought through in a way which can be expressed in language.

Logical Reasoning Problem

Reasoning as a process takes proposed explanations for considering, contrasting, or fitting them together in order to determine which beliefs, actions or attitudes are the best. Theoretical reasoning considers theoretical explanations in order to determine what to believe or accept as true. Practical reasoning considers what attitudes to have when taking actions.

Assessing how well someone engages in reasoning is the project of determining the extent to which the person is rational or acts rationally. It is a key research question in the psychology of reasoning. Rationality is often divided into its respective theoretical and practical counterparts.

Etymology

The meaning of the word "reason" in senses such as "human reason" overlaps to a large extent with "rationality" and the adjective of "reason" in philosophical contexts is normally "rational", rather than "reasoned" or "reasonable". The concept of "reason" is closely related to the concepts of language and logic, as reflected in the multiple meanings of the Greek *"λόγος" logos*, the root of logic, as per -logy, which translated into Latin became *ratio* (including mathematical ratio) and then in French *raison*, from which the English word "reason" was derived.

Reason compared to logic, cause-and-effect thinking, and symbolic thinking

In modern times, there is an increasing tendency to use the terms "logic" or "logical" as if they were identical with using reason or being "rational", or to see logic as the most pure or the defining form of reason.

Reason and logic can be thought of as distinct, although logic is one important aspect of reason. Reason is a type of thought. The word "logic" involves the attempt to describe rules by which reason operates, so that orderly reasoning can be taught. The oldest surviving writing to explicitly consider the rules by which reason operates are the works of the Greek philosopher Aristotle, especially *Prior Analysis* and *Posterior Analysis*.[2] Although the Ancient Greeks had no separate word for logic as distinct from language and reason, Aristotle's newly coined word "syllogism" (*syllogismos*) identified logic clearly for the first time as a distinct field of study. When Aristotle referred to "the logical" (*hē logikē*), he was referring more broadly to rational thought.[3]

Author Douglas Hofstadter, in *Gödel, Escher, Bach*, characterizes the distinction in this way. Logic is done inside a system while reason is done outside the system by such methods as skipping steps, working backward, drawing diagrams, looking at examples, or seeing what happens if you change the rules of the system.[4]

Another way to consider the confusion between logic and reason is that computers and animals sometimes perform actions which are apparently logical: from a complex set of data, conclusions are achieved which are "logical". Being a cause of something which humans find logical does not necessarily mean that computers or animals have reason, or even logic in the strict sense. Some animals are also clearly capable of a type of "associative thinking"—even to the extent of associating causes and effects.[5] A dog once kicked, can learn how to recognize the warning signs and avoid being kicked in the future. Human reason is something much more specific, requiring not just the possibility of associating perceptions of smoke, for example, with memories of fire, but also the ability to create and manipulate a system of symbols, as well as indices and icons, according to Charles Sanders Peirce, the symbols having only a nominal, though habitual, connection to either smoke or fire.[6]

Thomas Hobbes described the creation of "Markes, or Notes of remembrance" (*Leviathan* Ch.4) as "speech" (allowing by his definition that it is not necessarily a means of communication or speech in the normal sense; he was clearly using "speech" as an English version of *logos* in this description[7]). In the context of a language, these marks or notes are called "Signes" by Hobbes.

Reason, truth, and "first principles"

Since classical times a question has remained constant in philosophical debate (which is sometimes seen as a conflict between movements called Platonism and Aristotelianism) concerning the role of reason in confirming truth.

Both Aristotle and Plato, like many philosophers throughout history, wrote about this question, which can be explained as follows.

People use logic, deduction, and induction, to reach conclusions they think are true. Conclusions reached in this way are considered more certain than sense perceptions on their own.[8] On the other hand, if such reasoned conclusions are only built originally upon a foundation of sense perceptions, then, the argument being considered goes, our most logical conclusions can never be said to be certain because they are built upon the very same fallible perceptions they seek to better.[9]

This leads to the question of what types of first principles, or starting points of reasoning, are available for someone seeking to come to true conclusions. Empiricism (sometimes associated with Aristotle[10] but more correctly associated with British philosophers such as John Locke and David Hume, as well as their ancient equivalents such as Democritus) asserts that sensory impressions are the only available starting points for reasoning and attempting to attain truth. This approach always leads to the controversial conclusion that absolute knowledge is not attainable. Idealism, (associated with Plato and his school), claims that there is a "higher" reality, from which certain people can directly arrive at truth without needing to rely only upon the senses, and that this higher reality is therefore the primary source of truth. Whereas secular reason begins with observable reality and applies logic to it to derive conclusions, theological reason begins with a predetermined conclusion or unquestionable sacred text and verifies it by using logic to reinterpret or to reject observable reality.

In Greek, "first principles" are *archē*, "starting points",[11] and the faculty used to perceive them is sometimes referred to in Aristotle[12] and Plato[13] as *nous* which was close in meaning to "awareness" or "consciousness".[14]

Philosophers such as Plato, Aristotle, Al-Farabi, Avicenna, Averroes, Maimonides, Aquinas and Hegel are sometimes said to have argued that reason must be fixed and discoverable—perhaps by dialectic, analysis, or study. In the vision of these thinkers, reason is divine or at least has divine attributes. Such an approach allowed religious philosophers such as Thomas Aquinas and Étienne Gilson to try to show that reason and revelation are compatible. According to Hegel, "...the only thought which Philosophy bring with it to the contemplation of History, is the simple conception of reason; that reason is the Sovereign of the World; that the history of the world, therefore, presents us with a rational process."[15]

Since the 17th century rationalists, reason has often been taken to be a subjective faculty, or rather the unaided ability (pure reason) to form concepts. For Descartes, Spinoza and Leibniz, this was associated with mathematics. Kant attempted to show that pure reason could form concepts (time and space) that are the conditions of experience. Kant made his argument in opposition to Hume, who denied that reason had any role to play in experience.

Justifying reason itself

Stronger forms of Cartesian skepticism might well ask "Why use reason?". How a philosopher answers this question depends on their definition of Truth, particularly their Theory of justification. Ludwig Wittgenstein's ordinary language philosophy would at least have us deconstruct the question, for if it is taken to mean "What reasons are there to use reason?" then there can be no non-circular answer - there is no way of reasonably justifying reason. Agree upon first principles, including laws of logic, are necessary (see above). Language philosophy might then suggest that the asker is asserting that they accept the discussion's premise that rationality will be used (although they unknowingly ask an incoherent question) or else they are denying the premise. Pragmatism quickly points out the obvious that, if a person actually refuses to use reason, then rational discussion is impossible.

Reason, imagination, mimesis, and memory

Reason and imagination rely on similar mental processes.[16] Imagination is not only found in humans. But Aristotle, for example, stated that *phantasia* (imagination: that which can hold images or *phantasmata*) and *phronein* (a type of thinking which can judge and understand in some sense) also exist in some animals.[17] Both are related to the primary perceptive ability of animals, which gathers the perceptions of different senses and defines the order of the things that are perceived without distinguishing universals, and without deliberation or *logos*. This is equivalent to the habitual thinking about cause and effect discussed by Hume, and mentioned above. But this is not yet reason, because human imagination is different.

The recent modern writings of Terrence Deacon and Merlin Donald fit into an older tradition which makes reason connected to language, and mimesis,[18] but more specifically the ability to create language as part of an internal modeling of reality specific to humankind. Other results are consciousness, and imagination or fantasy. In more recent times, important areas of research include the relationship between reason and language, especially in discussions of origin of language. Modern proponents of *a priori* reasoning, at least with regards to language, include Noam Chomsky and Steven Pinker, to whom Donald and Deacon can be usefully contrasted.

If reason is symbolic thinking, and peculiarly human, then this implies that humans have a special ability to maintain a clear consciousness of the distinctness of "icons" or images and the real things they represent. Starting with a modern author, Merlin Donald writes[19]

> A dog might perceive the "meaning" of a fight that was realistically play-acted by humans, but it could not reconstruct the message or distinguish the representation from its referent (a real fight). [...] Trained apes are able to make this distinction; young children make this distinction early – hence, their effortless distinction between play-acting an event and the event itself

What Donald refers to here can be compared to Plato's term, *eikasia* as explained for example in Jacob Klein's commentary on Plato's dialog concerning learning, the *Meno*, which contains a long digression on this subject.[20] According to this, an important aspect of human thinking in the Ancient Greek philosophical terminology of Plato is *eikasia*. This is the ability to perceive whether a perception is an image of something else, related somehow but not the same, and which therefore allows us to perceive that a dream or memory or a reflection in a mirror is not reality as such. What Klein refers to as *dianoetic eikasia* is the *eikasia* concerned specifically with thinking and mental images, such as those mental symbols, icons, "signes" and marks which are discussed above as definitive of reason. Explaining reason from this direction: human thinking is special in the way that we often understand visible things as if they were themselves images of our intelligible "objects of thought" as "foundations" (*hypothēses* in Ancient Greek). This thinking (*dianoia*) is "an activity which consists in making the vast and diffuse jungle of the visible world depend on a plurality of more 'precise' *noēta*".[21]

In turn, both Merlin Donald and the Socratic authors emphasize the importance of *mimesis*, often translated as "imitation". Donald writes[22]

> Imitation is found especially in monkeys and apes [... but ...] Mimesis is fundamentally different from imitation and mimicry in that it involves the invention of intentional representations. [...] Mimesis is not absolutely tied to external communication.

Mimēsis is a concept, now popular again in academic discussion, which was particularly prevalent in Plato's works, and within Aristotle, it is discussed mainly in the *Poetics*. In Michael Davis's account of the theory of man in this work.[23]

> It is the distinctive feature of human action, that whenever we choose what we do, we imagine an action for ourselves as though we were inspecting it from the outside. Intentions are nothing more than imagined actions, internalizings of the external. All action is therefore imitation of action; it is poetic...

...Thus Davis is here using "poetic" in an unusual sense, questioning the contrast in Aristotle between action (*praxis*, the *praktikē*) and making (*poēsis*, the *poētikē*)...

> ...Human [peculiarly human] action is imitation of action because thinking is always rethinking. Aristotle can define human beings as at once rational animals, political animals, and imitative animals because in the end the three are the same.

We can also note that Donald also shares with Plato and Aristotle (especially in *On Memory and Recollection*), an emphasis upon the peculiarity in humans of voluntary initiation of a search through one's mental world. The ancient Greek *anamnēsis*, normally translated as "recollection" was opposed to *mneme* or "memory". Memory, shared with some animals,[24] requires a consciousness not only of what happened in the past, but also *that* something happened in the past, which is in other words a kind of *eikasia*[25] "but nothing except man is able to recollect".[26] Recollection is a deliberate effort to search for and recapture something which was once known. Klein writes that, to "become aware of our having forgotten something means to begin recollecting".[27]

Donald calls the same thing "autocueing", which he explains as follows:[28]

> Mimetic acts are reproducible on the basis of internal, self-generated cues. This permits voluntary recall of mimetic representations, without the aid of external cues – probably the earliest form of representational "thinking".

In a celebrated paper on this subject of modern times, the fantasy author and philologist J.R.R. Tolkien wrote in his essay "On Fairy Stories" that the terms "fantasy" and "enchantment" are connected to not only "the satisfaction of certain primordial human desires" but also "the origin of language and of the mind".

Reason and emotion or passion

In western literature, reason is often opposed to emotions or feelings—desires, fears, hates, drives, or passions. Even in everyday speech, westerners tend to say for example that their passions made them behave contrary to reason, or that their reason kept the passions under control (often expressed in colloquial terms as the dilemma between following "the head" (reason) "or the heart" (emotions)) . Many writers, such as Nikos Kazantzakis, extol passion and disparage reason.

It has also become common, particularly since the writings of Freud, to describe reason as the servant of the passions—the means of sorting out our desires and then getting what we want, or perhaps even the slave of the passions—allowing us to pretend to reason to the object of our desire. Such feigned reason is called "rationalization".

Philosophers such as Plato, Rousseau, Hume, Kierkegaard, and Nietzsche have combined both views—making rational thinking not only a tool of desires, but also something privileged within the spectrum of desires, being itself desired, and not only because of its usefulness in satisfying other desires.

Modern psychology has much to say on the role of emotions in belief formation. Deeper philosophical questions about the relation between belief and reality are studied in the field of epistemology, which forms part of the philosophical basis of science, a branch of human activity that specifically aims to determine (certain types of) truth by methods that avoid dependence on the emotions of the researchers.

Reason in political philosophy and ethics

Near the beginning of political philosophy, Aristotle famously described reason (with language) as a part of human nature which means that it is best for humans to live "politically" meaning in communities of about the size and type of a small city state (*polis* in Greek). For example...

> It is clear, then, that a human being is more of a political [*politikon* = of the *polis*] animal [*zōion*] than is any bee or than any of those animals that live in herds. For nature, as we say, makes nothing in vain, and humans are the only animals who possess reasoned speech [*logos*]. Voice, of course, serves to indicate what is painful and pleasant; that is why it is also found in other animals, because their nature has reached the point where they can perceive what is painful and pleasant and express these to each other. But speech [*logos*] serves to make plain what is advantageous and harmful and so also what is just and

> unjust. For it is a peculiarity of humans, in contrast to the other animals, to have perception of good and bad, just and unjust, and the like; and the community in these things makes a household or city [*polis*]. [...] By nature, then, the drive for such a community exists in everyone, but the first to set one up is responsible for things of very great goodness. For as humans are the best of all animals when perfected, so they are the worst when divorced from law and right. The reason is that injustice is most difficult to deal with when furnished with weapons, and the weapons a human being has are meant by nature to go along with prudence and virtue, but it is only too possible to turn them to contrary uses. Consequently, if a human being lacks virtue, he is the most unholy and savage thing, and when it comes to sex and food, the worst. But justice is something political [to do with the *polis*], for right is the arrangement of the political community, and right is discrimination of what is just. (Aristotle's Politics 1253a 1.2. Peter Simpson's translation, with Greek terms inserted in square brackets.)

The concept of human nature being fixed in this way, implied, in other words, that we can define what type of community is always best for people. This argument has remained a central argument in all political, ethical and moral thinking since then, and has become especially controversial since firstly Rousseau's Second Discourse, and secondly, the Theory of Evolution. Already in Aristotle there was an awareness that the *polis* had not always existed and had needed to be invented or developed by humans themselves. The household came first, and the first villages and cities were just extensions of that, with the first cities being run as if they were still families with Kings acting like fathers.[29] ...

> Friendship [*philia*] seems to prevail [in] man and woman according to nature [*kata phusin*]; for people are by nature [*tēi phusei*] pairing [*sunduastikon*] more than political [*politikon* = of the *polis*], inasmuch as the household [*oikos*] is prior [*proteron* = earlier] and more necessary than the *polis* and making children is more common [*koinoteron*] with the animals. In the other animals, community [*koinōnia*] goes no further than this, but people live together [*sumoikousin*] not only for the sake of making children, but also for the things for life; for from the start the functions [*erga*] are divided, and are different [for] man and woman. Thus they supply each other, putting their own into the common [*eis to koinon*]. It is for these [reasons] that both utility [*chrēsimon*] and pleasure [*hēdu*] seem to be found in this kind of friendship. (Nicomachean Ethics, VIII.12.1162a. Rough literal translation with Greek terms shown in square brackets.)

Rousseau in his Second Discourse finally took the shocking step of claiming that this traditional account has things in reverse: with reason, language and rationally organized communities all having developed over a long period of time merely as a result of the fact that some habits of cooperation were found to solve certain types of problems, and that once such cooperation became more important, it forced people to develop increasingly complex cooperation—often only in order to defend themselves from each other.

In other words, according to Rousseau, reason, language and rational community did not arise because of any conscious decision or plan by humans or gods, nor because of any pre-existing human nature. As a result, he claimed, living together in rationally organized communities like modern humans is a development which has many negative aspects compared to the original state of man as an ape. If there be anything specifically human in this theory, it is the flexibility and adaptability of humans. This view of the animal origins of distinctive human characteristics later received support from Charles Darwin's Theory of Evolution.

The two competing theories concerning the origins of reason are relevant to political and ethical thought because according to the Aristotelian theory, there is a best way of living together which exists independently of historical circumstances. According to Rousseau, we should even doubt that reason, language and politics are a good thing, as opposed to being simply the best option given the particular course of events which lead to today. Rousseau's theory, that human nature is malleable rather than fixed, is often taken to imply, for example by Karl Marx, a wider range of possible ways of living together than traditionally known.

However, while Rousseau's initial impact encouraged bloody revolutions against traditional politics, including both the French Revolution and the Russian Revolution, his own conclusions about the best forms of community seem to have been remarkably classical, in favor of city-states such as Geneva, and rural living.

Reason and faith

Though theologies and religions typically do not claim to be irrational, there is often a perceived conflict or tension between faith and tradition on the one hand, and reason on the other, as potentially competing sources of wisdom, law and truth. Defenders of traditions and faiths from claims that they are irrationalist for ignoring or even attempting to forbid reason and argument concerning some subjects, typically maintain that there is no real conflict with reason, because reason itself is not enough to explain such things as the origins of the universe, or right and wrong, and so reason can and should be complemented by other sources of knowledge. The counter claim to this is that such a defense does not logically explain why arguments from reason would be forbidden or ignored.

There are enormously wide differences between different faiths, or even schools within different faiths, concerning this matter.

Some commentators have claimed that Western civilization can be almost defined by its serious testing of the limits of tension between "unaided" reason and faith in "revealed" truths—figuratively summarized as Athens and Jerusalem, respectively. Leo Strauss spoke of a "Greater West" which included all areas under the influence of the tension between Greek rationalism and Abrahamic revelation, including the Muslim lands. He was particularly influenced by the great Muslim philosopher Al-Farabi. In order to consider to what extent Eastern philosophy might have partaken of these important tensions, it is perhaps best to consider whether dharma or tao may be equivalent to Nature (by which we mean *physis* in Greek). According to Strauss[30] the beginning of philosophy involved the "discovery or invention of nature" and the "pre-philosophical equivalent of nature" was supplied by "such notions as 'custom' or 'ways'" which appear to be "really universal" "in all times and places". The philosophical concept of nature or natures as a way of understanding *archē* (first principles of knowledge) brought about a peculiar tension between reasoning on the one hand, and tradition or faith on the other.

A Hindu approach to faith and reason is summarized by Swami Tripurari:

> Faith fully understood amounts to conformity to truth, whereas rational thought is but an imperfect means of apprehending truth. Conforming to truth involves apprehending or understanding it theoretically, but theoretically understanding truth does not necessarily involve conforming to it.[31]

See also

- Conscience
- Consciousness
- Deism
- Empiricism
- Epistemology
- Fideism
- Fantasy
- Foucault/Habermas debate
- Inquiry
- Logic
- Language
- Mimesis
- Mind
- Nous

- Practical reason
- Rationality
- Rationality and power
- Reasoning
- Speculative reason

Further reading

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- Tripurari, Swami, *On Faith and Reason* [32], *The Harmonist* [33], May 27, 2009.

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[3] See this Perseus search, and compare English translations. (http://www.perseus.tufts.edu/hopper/searchresults?all_words=logiko/s&all_words_expand=yes&la=greek) and see LSJ dictionary entry for λογικός, section II.2.b. (http://www.perseus.tufts.edu/hopper/morph.jsp?l=logikw=s&la=greek&prior=le/getai&d=Perseus:text:1999.01.0049:book=1:section=1217b&i=1#lexicon)
[4] Douglas Hofstadter, *Gödel, Escher, Bach*, Vintage, 1979, ISBN 0-394-74502-7
[5] See the Treatise of Human Nature of David Hume, Book I, Part III, Sect. XVI
[6] Terrence Deacon, *The Symbolic Species: The Co-Evolution of Language and the Brain*, W.W. Norton & Company, 1998, ISBN 0-393-31754-4
[7] Leviathan Chapter IV (http://oregonstate.edu/instruct/phl302/texts/hobbes/leviathan-a.html#CHAPTERIV): "The Greeks have but one word, logos, for both speech and reason; not that they thought there was no speech without reason, but no reasoning without speech"
[8] Example: Metaphysics 981b: τὴν ὀνομαζομένην σοφίαν περὶ τὰ πρῶτα αἴτια καὶ τὰς ἀρχὰς ὑπολαμβάνουσι πάντες: ὥστε, καθάπερ εἴρηται πρότερον, ὁ μὲν ἔμπειρος τῶν ὁποιανοῦν ἐχόντων αἴσθησιν εἶναι δοκεῖ σοφώτερος, ὁ δὲ τεχνίτης τῶν ἐμπείρων, χειροτέχνου δὲ ἀρχιτέκτων, αἱ δὲ θεωρητικαὶ τῶν ποιητικῶν μᾶλλον. "...what is called Wisdom is concerned with the primary causes and principles, so that, as has been already stated, the man of experience is held to be wiser than the mere possessors of any power of sensation, the artist than the man of experience, the master craftsman than the artisan; and the speculative sciences to be more learned than the productive."
[9] Metaphysics 1009b ποῖα οὖν τούτων ἀληθῆ ἢ ψευδῆ, ἄδηλον: οὐθὲν γὰρ μᾶλλον τάδε ἢ τάδε ἀληθῆ, ἀλλ᾽ ὁμοίως. διὸ Δημόκριτός γέ φησιν ἤτοι οὐθὲν εἶναι ἀληθὲς ἢ ἡμῖν γ᾽ ἄδηλον. "Thus it is uncertain which of these impressions are true or false; for one kind is no more true than another, but equally so. And hence Democritus says1 that either there is no truth or we cannot discover it."
[10] However, the empiricism of Aristotle must certainly be doubted. For example in Metaphysics 1009b, cited above, he criticizes people who think knowledge might not be possible because "they say that the impression given through sense-perception is necessarily true; for it is on these grounds that both Empedocles and Democritus and practically all the rest have become obsessed by such opinions as these".
[11] For example Aristotle *Metaphysics* 983a: ἐπεὶ δὲ φανερὸν ὅτι τῶν ἐξ **ἀρχῆς** αἰτίων δεῖ λαβεῖν **ἐπιστήμην** （τότε γὰρ εἰδέναι φαμὲν ἕκαστον, ὅταν τὴν **πρώτην** αἰτίαν οἰώμεθα **γνωρίζειν**） "It is clear that we must obtain knowledge of the **primary** causes, because it is when we think that we understand its **primary** cause that we claim to **know** each particular thing."
[12] Example: *Nicomachean Ethics* 1139b: ἀμφοτέρων δὴ τῶν **νοητικῶν** μορίων ἀλήθεια τὸ ἔργον. καθ᾽ ἃς οὖν μάλιστα ἕξεις ἀληθεύσει ἑκάτερον, αὗται ἀρεταὶ ἀμφοῖν. The attainment of truth is then the function of both the **intellectual** parts of the soul. Therefore their respective virtues are those dispositions which will best qualify them to attain truth.
[13] Example: Plat. Rep. 490b μιγεὶς τῷ ὄντι ὄντως, γεννήσας νοῦν καὶ ἀλήθειαν, γνοίη "consorting with reality really, he would beget intelligence and truth, attain to knowledge"
[14] "This quest for the beginnings proceeds through sense perception, reasoning, and what they call *noesis*, which is literally translated by "understanding" or intellect," and which we can perhaps translate a little bit more cautiously by "awareness," an awareness of the mind's eye as distinguished from sensible awareness." "Progress or Return" in An Introduction to Political Philosophy: Ten Essays by Leo Strauss. (Expanded version of Political Philosophy: Six Essays by Leo Strauss, 1975.) Ed. Hilail Gilden. Detroit: Wayne State UP, 1989.
[15] G.W.F. Hegel *The Philosophy of History*, p. 9, Dover Publications Inc., ISBN 0-486-20112-0; 1st ed. 1899
[16] See for example Ruth M.J. Byrne (2005). *The Rational Imagination: How People Create Counterfactual Alternatives to Reality.* Cambridge, MA: MIT Press.
[17] *De Anima* III.i-iii; *On Memory and Recollection*, *On Dreams*
[18] It should be noted that mimesis in modern academic writing, starting with Erich Auerbach, is a technical word, which is not necessarily exactly the same in meaning as the original Greek. See Mimesis.
[19] Origins of the Modern Mind p.172
[20] Ch.5

[21] Jacob Klein *A Commentary on the Meno* p.122
[22] Origins of the Modern Mind p.169
[23] "Introduction" to the translation of *Poetics* by Davis and Seth Benardete p. xvii, xxviii
[24] Aristotle On Memory 450a 15-16.
[25] Klein p.109
[26] Aristotle Hist. Anim. I.1.488b.25-26.
[27] Jacob Klein *A Commentary on the Meno* p. 112
[28] *The Origins of the Modern Mind* p.173 see also *A Mind So Rare* p.140-1
[29] Politics I.2.1252b15
[30] "Progress or Return" in An Introduction to Political Philosophy: Ten Essays by Leo Strauss. (Expanded version of Political Philosophy: Six Essays by Leo Strauss, 1975.) Ed. Hilail Gilden. Detroit: Wayne State UP, 1989.
[31] Tripurari, Swami, *On Faith and Reason* (http://harmonist.us/2009/05/on-faith-and-reason/), *The Harmonist* (http://harmonist.us/), May 27, 2009.
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Footnotes

Reasoning

Reasoning is the cognitive process of looking for reasons, beliefs, conclusions, actions or feelings.[1]

Different forms of such reflection on reasoning occur in different fields. In philosophy, the study of reasoning typically focuses on what makes reasoning efficient or inefficient, appropriate or inappropriate, good or bad. Philosophers do this by either examining the form or structure of the reasoning within arguments, or by considering the broader methods used to reach particular goals of reasoning. Psychologists and cognitive scientists, in contrast, tend to study how people reason, which cognitive and neural processes are engaged, how cultural factors affect the inferences people draw. The properties of logic which may be used to reason are studied in mathematical logic. The field of automated reasoning studies how reasoning may be modelled computationally. Lawyers also study reasoning.

History of reasoning

It is likely that humans have used reasoning to work out what they should believe or do for a very long time. However, some researchers have tried to determine when, in the history of human development, humans began using formal techniques of reasoning.

Babylonian reasoning

In Mesopotamia, Esagil-kin-apli's medical *Diagnostic Handbook* written in the 11th century BC was based on a logical set of axioms and assumptions, including the modern view that through the examination and inspection of the symptoms of a patient, it is possible to determine the patient's disease, its aetiology and future development, and the chances of the patient's recovery.[2]

During the 8th and 7th centuries BC, Babylonian astronomers began employing an internal logic within their predictive planetary systems, which was an important contribution to logic and the philosophy of science.[3] Babylonian thought had a considerable influence on early Greek thought.[4]

Greek reasoning

The works of Homer, written in the 8th century BC, contain mythic stories that use gods to explain the formation of the world. However, only two centuries later, late in the 6th century BC, Xenophanes of Colophon began to question the Homeric accounts of the creation of nature and the gods. He wrote:

- "Homer and Hesiod attribute all things to the gods that among men are shame and a disgrace" (frag. 11).
- "God is one, greatest among gods and among men, in no way like men in form and thought" (frag. 23).
- "If oxen and horses and lions had hands or could paint and make things with their hands like men, then they would paint the forms of gods and make their bodies each according to their own shapes, horses like horses, oxen like oxen" (frag. 15).

According to David Furley, "the basis of [Xenophanes'] criticism appears to have been that he saw an inconsistency between the concept of god as something different from man, and the stories told about the gods, which made them behave as men do."[5] In the same period, other Greek thinkers began to develop theories about the nature of the world that suggest that they believed that there were regularities in nature and that humans could use reasoning to develop a consistent story about the nature of the world. Thales of Miletus, c. 624 BC – c. 546 BC, proposed that all is water. Anaximenes of Miletus, c. 585 BC – c. 525 BC, claimed that air is the source of everything.[5]

Aristotle is, so far as we know, the first writer to give an extended, systematic treatment of the methods of human reasoning. He identified two major methods of reasoning, analysis and synthesis. In the first, we try to understand an object by looking at its component parts. In the second, we try to understand a class of objects by looking at the common properties of each object in that class.

Aristotle developed what is known as syllogistic logic, which makes it possible to analyse reasoning in a way that ignores the content of the argument and focuses on the form or structure of the argument.[6] In the Prior Analytics, Aristotle begins by pointing out that:

> "[If] no pleasure is a good, neither will any good be a pleasure."[7]

He then argues that this argument is an example of a rule of reasoning of the following form:

> Premise: "Aristotle is Greek" and "All Greeks are human"
>
> Conclusion: "Aristotle is human"

Aristotle points out that by understanding the reasoning involved in this type of argument, we can know that whatever the As and Bs are, we can reach the same conclusion about the relationship between them. This is a simple and straightforward argument, but it is a sign of an amazing leap in understanding and research into reason and was the beginning of the development of formal logic.

Aristotle's system of logic was responsible for the introduction of hypothetical syllogism,[8] temporal modal logic,[9][10] and inductive logic.[11]

Indian reasoning

Two of the six Indian schools of thought deal with logic: Nyaya and Vaisheshika. The Nyaya Sutras of Aksapada Gautama constitute the core texts of the Nyaya school, one of the six orthodox schools of Hindu philosophy. This realist school developed a rigid five-member schema of inference involving an initial premise, a reason, an example, an application and a conclusion. The idealist Buddhist philosophy became the chief opponent to the Naiyayikas. Nagarjuna, the founder of the Madhyamika "Middle Way" developed an analysis known as the "catuskoti" or tetralemma. This four-cornered argumentation systematically examined and rejected the affirmation of a proposition, its denial, the joint affirmation and denial, and finally, the rejection of its affirmation and denial. But it was with Dignaga and his successor Dharmakirti that Buddhist logic reached its height. Their analysis centred on the definition of necessary logical entailment, "vyapti", also known as invariable concomitance or pervasion. To this end a doctrine known as "apoha" or differentiation was developed. This involved what might be called inclusion and exclusion of defining properties. The difficulties involved in this enterprise, in part, stimulated the neo-scholastic school of Navya-Nyāya, which developed a formal analysis of inference in the 16th century.

Chinese reasoning

In China, a contemporary of Confucius, Mozi, "Master Mo", is credited with founding the Mohist school, whose canons dealt with issues relating to valid inference and the conditions of correct conclusions. In particular, one of the schools that grew out of Mohism, the Logicians, are credited by some scholars for their early investigation of formal logic. However, due to the harsh rule of Legalism in the subsequent Qin Dynasty, this line of investigation disappeared in China until the introduction of Indian philosophy by Buddhists.

Islamic reasoning

For a time after prophet Muhammad's death, Islamic law placed importance on formulating standards of argument, which gave rise to a novel approach to logic in Kalam, but this approach was later influenced by ideas from Greek philosophy and Hellenistic philosophy with the rise of the Mu'tazili philosophers, who highly valued Aristotle's *Organon*. The works of Hellenistic-influenced Islamic philosophers were crucial in the reception of Aristotelian logic in medieval Europe, along with the commentaries on the *Organon* by Averroes. The works of al-Farabi, Avicenna, al-Ghazali and other Muslim logicians who often criticized and corrected Aristotelian logic and introduced their own forms of logic, also played a central role in the subsequent development of medieval European logic.

Islamic logic not only included the study of formal patterns of inference and their validity but also elements of the philosophy of language and elements of epistemology and metaphysics. Due to disputes with Arabic grammarians, Islamic philosophers were very interested in working out the relationship between logic and language, and they devoted much discussion to the question of the subject matter and aims of logic in relation to reasoning and speech. In the area of formal logical analysis, they elaborated upon the theory of terms, propositions and syllogisms. They considered the syllogism to be the form to which all rational argumentation could be reduced, and they regarded syllogistic theory as the focal point of logic. Even poetics was considered as a syllogistic art in some fashion by many major Islamic logicians.

Important developments made by Muslim logicians included the development of "Avicenna's logic" as a replacement of Aristotelian logic. Other important developments in Islamic philosophy include the development of a strict citation practice, the isnad or "backing", and the development of a scientific method of open inquiry to disprove claims, the ijtihad, which could be generally applied to many types of questions.

Reasoning methods and argumentation

One approach to the study of reasoning is to identify various forms of reasoning that may be used to support or justify conclusions. The main division between forms of reasoning that is made in philosophy is between deductive reasoning and inductive reasoning. Formal logic has been described as "the science of deduction".[12] The study of inductive reasoning is generally carried out within the field known as informal logic or critical thinking.

Deductive reasoning

Reasoning in an argument is valid if the argument's conclusion must be true when the premises (the reasons given to support that conclusion) are true. One classic example of deductive reasoning is that found in syllogisms like the following:

Premise 1: All humans are mortal.

Premise 2: Socrates is a human.

Conclusion: Socrates is mortal.

The reasoning in this argument is valid, because there is no way in which the premises, 1 and 2, could be true and the conclusion, 3, be false.

Validity is a property of the reasoning in the argument, not a property of the premises in the argument or the argument as a whole. In fact, the truth or falsity of the premises and the conclusion is irrelevant to the validity of the reasoning in the argument. The following argument, with a false premise and a false conclusion, is also valid (it has the form of reasoning known as modus ponens).

Premise 1: If green is a color, then grass poisons cows.

Premise 2: Green is a color.

Conclusion: Grass poisons cows.

Again, if the premises in this argument were true, the reasoning is such that the conclusion would also have to be true.

In a deductive argument with valid reasoning the conclusion contains no more information than is contained in the premises. Therefore, deductive reasoning does not increase one's knowledge base, and so is said to be non-ampliative.

Within the field of formal logic, a variety of different forms of deductive reasoning have been developed. These involve abstract reasoning using symbols, logical operators and a set of rules that specify what processes may be followed to arrive at a conclusion. These forms of reasoning include Aristotelian logic, also known as syllogistic logic, propositional logic, predicate logic, and modal logic.

Inductive reasoning

Induction is a form of inference producing propositions about unobserved objects or types, either specifically or generally, based on previous observation. It is used to ascribe properties or relations to objects or types based on previous observations or experiences, or to formulate general statements or laws based on limited observations of recurring phenomenal patterns.

Inductive reasoning contrasts strongly with deductive reasoning in that, even in the best, or strongest, cases of inductive reasoning, the truth of the premises does not guarantee the truth of the conclusion. Instead, the conclusion of an inductive argument follows with some degree of probability. Relatedly, the conclusion of an inductive argument contains more information than is already contained in the premises. Thus, this method of reasoning is ampliative.

A classic example of inductive reasoning comes from the empiricist David Hume:

Premise: The sun has risen in the east every morning up until now.

Conclusion: The sun will also rise in the east tomorrow.

Abductive reasoning

Abductive reasoning, or argument to the best explanation, is a form of inductive reasoning, since the conclusion in an abductive argument does not follow with certainty from its premises and concerns something unobserved. What distinguishes abduction from the other forms of reasoning is an attempt to favour one conclusion above others, by attempting to falsify alternative explanations or by demonstrating the likelihood of the favoured conclusion, given a set of more or less disputable assumptions. For example, when a patient displays certain symptoms, there might be various possible causes, but one of these is preferred above others as being more probable.

Analogical reasoning

Analogical reasoning is reasoning from the particular to the particular. An example follows:

Premise 1: Socrates is human and Socrates died.

Premise 2: Plato is human.

Conclusion: Plato will die.

Analogical reasoning can be viewed as a form of inductive reasoning, since the truth of the premises does not guarantee the truth of the conclusion. However, the traditional view is that inductive reasoning is reasoning from the particular to the general, and thus analogical reasoning is distinct from inductive reasoning.[13] An example of inductive reasoning from the particular to the general follows:

Premise 1: Socrates is human and Socrates died.

Premise 2: Plato is human and Plato died.

Premise 3: Aristotle is human and Aristotle died.

Conclusion: All humans die.

It has been argued that deductive, inductive, and abductive reasoning are all based on a foundation of analogical reasoning.[14]

Fallacious reasoning

Flawed reasoning in arguments is known as fallacious reasoning. Reasoning within arguments can be bad because it commits either a formal fallacy or an informal fallacy.

Formal fallacies

Formal fallacies occur when there is a problem with the form, or structure, of the argument. The word "formal" refers to this link to the *form* of the argument. An argument that contains a formal fallacy will always be invalid. Consider, for example, the following argument:

1. If a drink is made with boiling water, it will be hot.
2. This drink was not made with boiling water.
3. This drink is not hot.

The reasoning in this argument is bad, because the antecedent (first part) of the conditional (the "if..., then..." statement) can be false without the consequent (second half) of the conditional being true. In this example, the drink could have been made with boiling milk, or heated in the microwave, and so be hot in spite of the truth of statement 2. This particular formal fallacy is known as denying the antecedent.

Informal fallacies

An informal fallacy is an error in reasoning that occurs due to a problem with the *content*, rather than mere *structure*, of the argument. Reasoning that commits an informal fallacy often occurs in an argument that is invalid, that is, contains a formal fallacy. One example of such reasoning is a red herring argument.

An argument can be valid, that is, contain no formal reasoning fallacies, and yet still contain an informal fallacy. The clearest examples of this occur when an argument contains circular reasoning, also known as begging the question.

Psychology

Scientific research into reasoning is carried out within the fields of psychology and cognitive science. Psychologists attempt to determine whether or not people are capable of rational thought in various different circumstances.

Behavioral experiments on human reasoning

Experimental cognitive psychologists carry out research on reasoning behaviour. Such research may focus, for example, on how people perform on tests of reasoning such as intelligence or IQ tests, or on how well people's reasoning matches ideals set by logic (see, for example, the Wason test).[15] Experiments examine how people make inferences from conditionals e.g., *If A then B* and how they make inferences about alternatives, e.g., *A or else B*.[16] They test whether people can make valid deductions about spatial and temporal relations, e.g., *A is to the left of B*, or *A happens after B*, and about quantified assertions, e.g., *All the A are B*.[17] Experiments investigate how people make inferences about factual situations, hypothetical possibilities, probabilities, and counterfactual situations.[18]

Developmental studies of children's reasoning

Developmental psychologists investigate the development of reasoning from birth to adulthood. Piaget's theory of cognitive development was the first complete theory of reasoning development. Subsequently, several alternative theories were proposed, including the neo-Piagetian theories of cognitive development.[19]

Neuroscience of reasoning

The biological functioning of the brain is studied by neurophysiologists and neuropsychologists. Research in this area includes research into the structure and function of normally functioning brains, and of damaged or otherwise unusual brains. In addition to carrying out research into reasoning, some psychologists, for example, clinical psychologists and psychotherapists work to alter people's reasoning habits when they are unhelpful.

Automated reasoning

In artificial intelligence and computer science, scientists study and use automated reasoning for diverse applications including automated theorem proving the formal semantics of programming languages, and formal specification in software engineering.

Meta-reasoning

Meta-reasoning is reasoning about reasoning. In computer science, a system performs meta-reasoning when it is reasoning about its own operation.[20] This requires a programming language capable of reflection, the ability to observe and modify its own structure and behaviour.

Legal reasoning

Legal reasoning is used when reflecting on the nature of existing laws or when reaching decisions about the relationship between laws and particular court cases.

Thorne McCarty did pioneering early work in the mechanisation of legal reasoning for taxation using Micro Planner.[21] More recent work on the formalisation and mechanisation of legal reasoning can be found in the proceedings of the International Conferences on Artificial Intelligence and Law (most recently at Stanford in June 2007 [22]).

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See also

- Casuistry
- Categorical syllogism
- Critical thinking
- Defeasible reasoning
- Evidence
- Inference
- Logic
- Logical fallacy
- Logical reasoning
- Mill's Methods
- Practical reason
- Rationality
- Rationality and power
- Reason
- Recognition primed decision
- Retroduction
- Theoretical reason
- What the Tortoise Said to Achilles
- Rastafarian reasoning ceremony

Science

Science (from the Latin *scientia*, meaning "knowledge") is an enterprise that builds and organizes knowledge in the form of testable explanations and predictions about the natural world.[1] [2] [3] [4] An older meaning still in use today is that of Aristotle, for whom scientific knowledge was a body of reliable knowledge that can be logically and convincingly explained (*see "History and etymology" section below*).[5]

Since classical antiquity science as a type of knowledge was closely linked to philosophy, the way of life dedicated to discovering such knowledge. And into early modern times the two words, "science" and "philosophy", were sometimes used interchangeably in the English language. By the 17th century, "natural philosophy" (which is today called "natural science") could be considered separately from "philosophy" in general.[6] But "science" continued to also be used in a broad sense denoting reliable knowledge about a topic, in the same way it is still used in modern terms such as library science or political science.

The more narrow sense of "science" that is common today developed as a part of science became a distinct enterprise of defining "laws of nature", based on early examples such as Kepler's laws, Galileo's laws, and Newton's laws of motion. In this period it became more common to refer to natural philosophy as "natural science". Over the course of the 19th century, the word "science" became increasingly strongly associated with the disciplined study of the natural world including physics, chemistry, geology and biology. This sometimes left the study of human thought and society in a linguistic limbo, which was resolved by classifying these areas of academic study as social science. Similarly, several other major areas of disciplined study and knowledge exist today under the general rubric of "science", such as formal science and applied science.[7]

Basic classifications

Scientific fields are commonly divided into two major groups: natural sciences, which study natural phenomena (including biological life), and social sciences, which study human behavior and societies. These groupings are empirical sciences, which means the knowledge must be based on observable phenomena and capable of being tested for its validity by other researchers working under the same conditions.[2] There are also related disciplines that are grouped into interdisciplinary and applied sciences, such as engineering and medicine. Within these categories are specialized scientific fields that can include parts of other scientific disciplines but often possess their own terminology and expertise.[8]

Mathematics, which is classified as a formal science,[9] [10] has both similarities and differences with the empirical sciences (the natural and social sciences). It is similar to empirical sciences in that it involves an objective, careful and systematic study of an area of knowledge; it is different because of its method of verifying its knowledge, using *a priori* rather than empirical methods.[2] Formal science, which also includes statistics and logic, is vital to the empirical sciences. Major advances in formal science have often led to major advances in the empirical sciences. The formal sciences are essential in the formation of hypotheses, theories, and laws,[2] both in discovering and describing how things work (natural sciences) and how people think and act (social sciences).

History and etymology

Personification of "Science" in front of the Boston Public Library

It is widely accepted that 'modern science' arose in the Europe of the 17th century (towards the end of the Renaissance), introducing a new understanding of the natural world.[11] [12]

While descriptions of disciplined empirical investigations of the natural world exist from times at least as early as classical antiquity (for example, by Aristotle and Pliny the Elder), and scientific methods have been employed since the Middle Ages (for example, by Alhazen and Roger Bacon), the dawn of modern science is generally traced back to the early modern period during what is known as the Scientific Revolution of the 16th and 17th centuries.[11] This period was marked by a new way of studying the natural world, by methodical experimentation aimed at defining "laws of nature" while avoiding concerns with metaphysical concerns such as Aristotle's theory of causation.[13]

This modern science developed from an older and broader enterprise. The word "science" is from Old French, and in turn from Latin *scientia* which was one of several words for "knowledge" in that language.[14] [15] In philosophical contexts, *scientia* and "science" were used to translate the Greek word *epistemē*, which had acquired a specific definition in Greek philosophy, especially Aristotle, as a type of reliable knowledge which is built up logically from strong premises, and can be communicated and taught. In contrast to modern science, Aristotle's influential emphasis was upon the "theoretical" steps of deducing universal rules from raw data, and did not treat the gathering of experience and raw data as part of science itself.[16]

From the Middle Ages to the Enlightenment, science or *scientia* continued to be used in this broad sense, which was still common until the twentieth century.[17] "Science" therefore had the same sort of very broad meaning that *philosophy* had at that time. In other Latin influenced languages, including French, Spanish, Portuguese, and Italian, the word corresponding to *science* also carried this meaning.

Prior to the 18th century, the preferred term for the study of nature among English speakers was "natural philosophy", while other philosophical disciplines (e.g., logic, metaphysics, epistemology, ethics and aesthetics) were typically referred to as "moral philosophy". (Today, "moral philosophy" is more-or-less synonymous with "ethics".) Science only became more strongly associated with natural philosophy than other sciences gradually with the strong promotion of the importance of experimental scientific method, by people such as Francis Bacon. With Bacon, begins a more widespread and open criticism of Aristotle's influence which had emphasized theorizing and did not treat raw data collection as part of science itself. An opposed position became common: that what is critical to science at its best is methodical collecting of clear and useful raw data, something which is easier to do in some fields than others.

The word "science" in English was still however used in the 17th century to refer to the Aristotelian concept of knowledge which was secure enough to be used as a prescription for exactly how to accomplish a specific task. With respect to the transitional usage of the term "natural philosophy" in this period, the philosopher John Locke wrote disparagingly in 1690 that "natural philosophy is not capable of being made a science".[18]

Locke's assertion notwithstanding, by the early 19th century natural philosophy had begun to separate from philosophy, though it often retained a very broad meaning. In many cases, *science* continued to stand for reliable knowledge about any topic, in the same way it is still used today in the broad sense (see the introduction to this article) in modern terms such as library science, political science, and computer science. In the more narrow sense of *science*, as natural philosophy became linked to an expanding set of well-defined laws (beginning with Galileo's laws, Kepler's laws, and Newton's laws for motion), it became more popular to refer to natural philosophy as natural science. Over the course of the 19th century, moreover, there was an increased tendency to associate science with study of the natural world (that is, the non-human world). This move sometimes left the study of human thought and society (what would come to be called social science) in a linguistic limbo by the end of the century and into the next.[19]

Through the 19th century, many English speakers were increasingly differentiating science (i.e., the natural sciences) from all other forms of knowledge in a variety of ways. The now-familiar expression “scientific method,” which refers to the *prescriptive* part of how to make discoveries in natural philosophy, was almost unused until then, but became widespread after the 1870s, though there was rarely total agreement about just what it entailed.[19] The word "scientist," meant to refer to a systematically working natural philosopher, (as opposed to an intuitive or empirically minded one) was coined in 1833 by William Whewell.[20] Discussion of scientists as a special group of people who did science, even if their attributes were up for debate, grew in the last half of the 19th century.[19] Whatever people actually meant by these terms at first, they ultimately depicted science, in the narrow sense of the habitual use of the scientific method and the knowledge derived from it, as something deeply distinguished from all other realms of human endeavor.

By the 20th century, the modern notion of science as a special kind of knowledge about the world, practiced by a distinct group and pursued through a unique method, was essentially in place. It was used to give legitimacy to a variety of fields through such titles as "scientific" medicine, engineering, advertising, or motherhood.[19] Over the 20th century, links between science and technology also grew increasingly strong. As Martin Rees explains, progress in scientific understanding and technology have been synergistic and vital to one another.[21]

Richard Feynman described science in the following way for his students: "The principle of science, the definition, almost, is the following: *The test of all knowledge is experiment.* Experiment is the *sole judge* of scientific 'truth'. But what is the source of knowledge? Where do the laws that are to be tested come from? Experiment, itself, helps to produce these laws, in the sense that it gives us hints. But also needed is imagination to create from these hints the great generalizations — to guess at the wonderful, simple, but very strange patterns beneath them all, and then to experiment to check again whether we have made the right guess." Feynman also observed, "...there is an expanding frontier of ignorance...things must be learned only to be unlearned again or, more likely, to be corrected."[22]

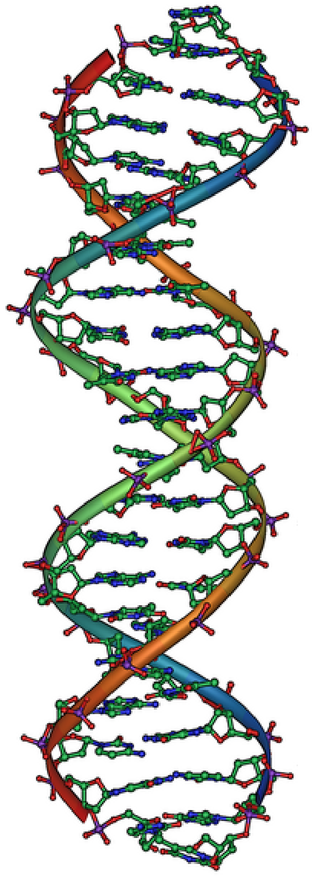
Scientific method

A scientific method seeks to explain the events of nature in a reproducible way, and to use these findings to make useful predictions. This is done partly through observation of natural phenomena, but also through experimentation that tries to simulate natural events under controlled conditions. Taken in its entirety, a scientific method allows for highly creative problem solving whilst minimizing any effects of subjective bias on the part of its users (namely the confirmation bias).[23]

Basic and applied research

Although some scientific research is applied research into specific problems, a great deal of our understanding comes from the curiosity-driven undertaking of basic research. This leads to options for technological advance that were not planned or sometimes even imaginable. This point was made by Michael Faraday when, allegedly in response to the question "what is the *use* of basic research?" he responded "Sir, what is the use of a new-born child?".[24] For example, research into the effects of red light on the human eye's rod cells did not seem to have any practical purpose; eventually, the discovery that our night vision is not troubled by red light would lead militaries to adopt red light in the cockpits of all jet fighters.[25] In a nutshell: Basic research is the search for knowledge. Applied research is the search for solutions.

Experimentation and hypothesizing

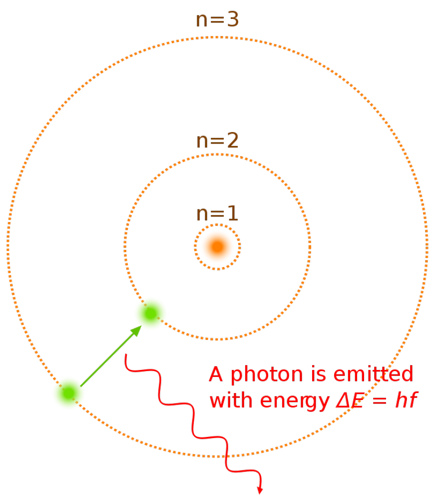


DNA determines the genetic structure of all known life

Based on observations of a phenomenon,scientists may generate a model.[26] This is an attempt to describe or depict the phenomenon in terms of a logical physical or mathematical representation. As empirical evidence is gathered, scientists can suggest a hypothesis to explain the phenomenon. Hypotheses may be formulated using principles such as parsimony (traditionally known as "Occam's Razor") and are generally expected to seek consilience - fitting well with other accepted facts related to the phenomena. This new explanation is used to make falsifiable predictions that are testable by experiment or observation. When a hypothesis proves unsatisfactory, it is either modified or discarded. Experimentation is especially important in science to help establish a causational relationships (to avoid the correlation fallacy). Operationalization also plays an important role in coordinating research in/across different fields.

Once a hypothesis has survived testing, it may become adopted into the framework of a scientific theory. This is a logically reasoned, self-consistent model or framework for describing the behavior of certain natural phenomena. A theory typically describes the behavior of much broader sets of phenomena than a hypothesis; commonly, a large number of hypotheses can be logically bound together by a single theory. Thus a theory is a hypothesis explaining various other hypotheses. In that vein, theories are formulated according to most of the same scientific principles as hypotheses.

While performing experiments, scientists may have a preference for one outcome over another, and so it is important to ensure that science



The Bohr model of the atom, like many ideas in the history of science, was at first prompted by (and later partially disproved by) experimentation.

as a whole can eliminate this bias.[27] [28] This can be achieved by careful experimental design, transparency, and a thorough peer review process of the experimental results as well as any conclusions.[29] [30] After the results of an experiment are announced or published, it is normal practice for independent researchers to double-check how the research was performed, and to follow up by performing similar experiments to determine how dependable the results might be.[31]

Certainty and science

Unlike a mathematical proof, a scientific theory is empirical, and is always open to falsification if new evidence is presented. That is, no theory is ever considered strictly certain as science works under a fallibilistic view. Instead, science is proud to make predictions with great probability, bearing in mind that the most likely event is not always what actually happens. During the Yom Kippur War, cognitive psychologist Daniel Kahneman was asked to explain why one squad of aircraft had returned safely, yet a second squad on the exact same operation had lost all of its planes. Rather than conduct a study in the hope of a new hypothesis, Kahneman simply reiterated the importance of expecting some coincidences in life, explaining that absurdly rare things, by definition, occasionally happen.[32]

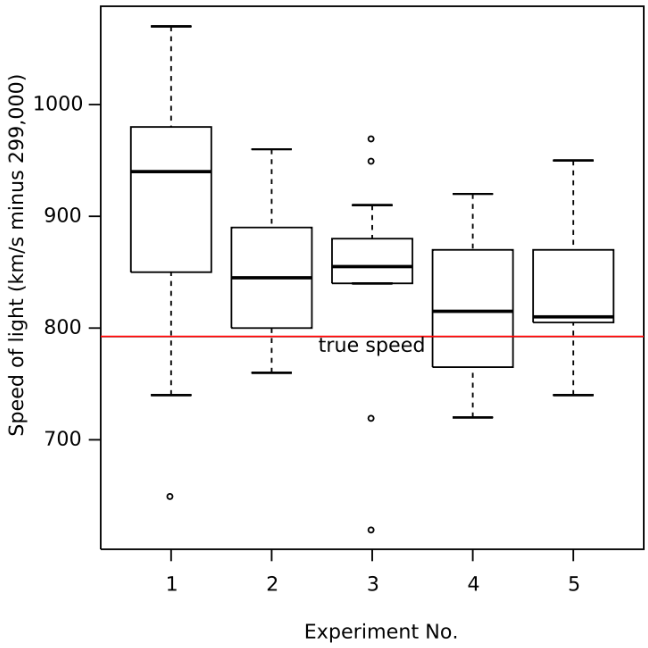
Although science values legitimate doubt, The Flat Earth Society is still widely regarded as an example of taking skepticism too far

Theories very rarely result in vast changes in our understanding. According to psychologist Keith Stanovich, it may be the media's overuse of words like "breakthrough" that leads the public to imagine that science is constantly proving everything it thought was true to be false.[33] While there are such famous cases as the theory of relativity that required a complete reconceptualization, these are extreme exceptions. Knowledge in science is gained by a gradual synthesis of information from different experiments, by various researchers, across different domains of science; it is more like a climb than a leap.[34] Theories vary in the extent to which they have been tested and verified, as well as their acceptance in the scientific community. For example, heliocentric theory, the theory of evolution, and germ theory still bear the name "theory" even though, in practice, they are considered factual.[35] Philosopher Barry Stroud adds that, although the best definition for "knowledge" is contested, being skeptical and entertaining the *possibility* that one is incorrect is compatible with being correct. Ironically then, the scientist adhering to proper scientific method will doubt themselves even once they possess the truth.[36] The fallibilist C. S. Peirce argued that inquiry is the struggle to resolve actual doubt and that merely quarrelsome, verbal, or hyperbolic doubt is fruitless[37] —but also that the inquirer should try to attain genuine doubt rather than resting uncritically on common sense.[38] He held that the successful sciences trust, not to any single chain of inference (no stronger than its weakest link), but to the cable of multiple and various arguments intimately connected.[39]

Stanovich also asserts that science avoids searching for a "magic bullet"; it avoids the single cause fallacy. This means a scientist would not ask merely "What is *the* cause of...", but rather "What *are* the most significant *causes* of...". This is especially the case in the more macroscopic fields of science (e.g. psychology, cosmology).[40] Of course, research often analyzes few factors at once, but this always to add to the long list of factors that are most important to consider.[40] For example: knowing the details of only a person's genetics, or their history and upbringing, or the current situation may not explain a behaviour, but a deep understanding of all these variables combined can be very predictive.

Mathematics

Mathematics is essential to the sciences. One important function of mathematics in science is the role it plays in the expression of scientific *models*. Observing and collecting measurements, as well as hypothesizing and predicting, often require extensive use of mathematics. Arithmetic, algebra, geometry, trigonometry and calculus, for example, are all essential to physics. Virtually every branch of mathematics has applications in science, including "pure" areas such as number theory and topology.



Data from the famous Michelson–Morley experiment

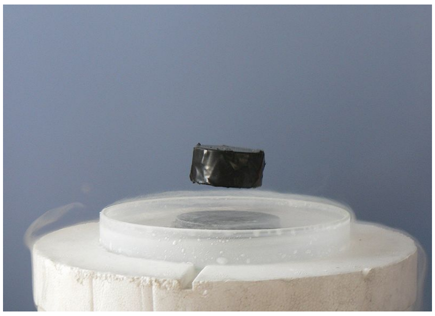
Statistical methods, which are mathematical techniques for summarizing and analyzing data, allow scientists to assess the level of reliability and the range of variation in experimental results. Statistical analysis plays a fundamental role in many areas of both the natural sciences and social sciences.

Computational science applies computing power to simulate real-world situations, enabling a better understanding of scientific problems than formal mathematics alone can achieve. According to the Society for Industrial and Applied Mathematics, computation is now as important as theory and experiment in advancing scientific knowledge.[41]

Whether mathematics itself is properly classified as science has been a matter of some debate. Some thinkers see mathematicians as scientists, regarding physical experiments as inessential or mathematical proofs as equivalent to experiments. Others do not see mathematics as a science, since it does not require an experimental test of its theories and hypotheses. Mathematical theorems and formulas are obtained by logical derivations which presume axiomatic systems, rather than the combination of empirical observation and logical reasoning that has come to be known as scientific method. In general, mathematics is classified as formal science, while natural and social sciences are classified as empirical sciences.[42]

Scientific community

The scientific community consists of the total body of scientists, its relationships and interactions. It is normally divided into "sub-communities" each working on a particular field within science.



The Meissner effect causes a magnet to levitate above a superconductor

Fields

Fields of science are widely recognized categories of specialized expertise, and typically embody their own terminology and nomenclature. Each field will commonly be represented by one or more scientific journal, where peer reviewed research will be published.

Institutions

Louis XIV visiting the Académie des sciences in 1671

Learned societies for the communication and promotion of scientific thought and experimentation have existed since the Renaissance period.[43] The oldest surviving institution is the *Accademia dei Lincei* in Italy.[44] National Academy of Sciences are distinguished institutions that exist in a number of countries, beginning with the British Royal Society in 1660[45] and the French *Académie des Sciences* in 1666.[46]

International scientific organizations, such as the International Council for Science, have since been formed to promote cooperation between the scientific communities of different nations. More recently, influential government agencies have been created to support scientific research, including the National Science Foundation in the U.S.

Other prominent organizations include the National Scientific and Technical Research Council in Argentina, the academies of science of many nations, CSIRO in Australia, Centre national de la recherche scientifique in France, Max Planck Society and Deutsche Forschungsgemeinschaft in Germany, and in Spain, CSIC.

Literature

An enormous range of scientific literature is published.[47] Scientific journals communicate and document the results of research carried out in universities and various other research institutions, serving as an archival record of science. The first scientific journals, *Journal des Sçavans* followed by the *Philosophical Transactions*, began publication in 1665. Since that time the total number of active periodicals has steadily increased. As of 1981, one estimate for the number of scientific and technical journals in publication was 11,500.[48] Today Pubmed lists almost 40,000, related to the medical sciences only.[49]

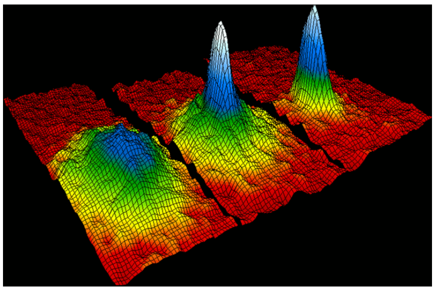
Most scientific journals cover a single scientific field and publish the research within that field; the research is normally expressed in the form of a scientific paper. Science has become so pervasive in modern societies that it is generally considered necessary to communicate the achievements, news, and ambitions of scientists to a wider populace.

Science magazines such as New Scientist, Science & Vie and Scientific American cater to the needs of a much wider readership and provide a non-technical summary of popular areas of research, including notable discoveries and advances in certain fields of research. Science books engage the interest of many more people. Tangentially, the science fiction genre, primarily fantastic in nature, engages the public imagination and transmits the ideas, if not the methods, of science.

Recent efforts to intensify or develop links between science and non-scientific disciplines such as Literature or, more specifically, Poetry, include the *Creative Writing Science* resource developed through the Royal Literary Fund.[50]

Philosophy of science

The philosophy of science seeks to understand the nature and justification of scientific knowledge. It has proven difficult to provide a definitive account of scientific method that can decisively serve to distinguish science from non-science. Thus there are legitimate arguments about exactly where the borders are, which is known as the problem of demarcation. There is nonetheless a set of core precepts that have broad consensus among published philosophers of science and within the scientific community at large. For example, it is universally agreed that scientific hypotheses and theories must be capable of being independently tested and verified by other scientists in order to become accepted by the scientific community.



Velocity-distribution data of a gas of rubidium atoms, confirming the discovery of a new phase of matter, the Bose–Einstein condensate

There are different schools of thought in the philosophy of scientific method. Methodological naturalism maintains that scientific investigation must adhere to empirical study and independent verification as a process for properly developing and evaluating natural explanations for observable phenomena.[51] Methodological naturalism, therefore, rejects supernatural explanations, arguments from authority and biased observational studies. Critical rationalism instead holds that unbiased observation is not possible and a demarcation between natural and supernatural explanations is arbitrary; it instead proposes falsifiability as the landmark of empirical theories and falsification as the universal empirical method. Critical rationalism argues for the ability of science to increase the scope of testable knowledge, but at the same time against its authority, by emphasizing its inherent fallibility. It proposes that science should be content with the rational elimination of errors in its theories, not in seeking for their verification (such as claiming certain or probable proof or disproof; both the proposal and falsification of a theory are only of methodological, conjectural, and tentative character in critical rationalism).[52] Instrumentalism rejects the concept of truth and emphasizes merely the utility of theories as instruments for explaining and predicting phenomena.[53]

Biologist Stephen J. Gould maintained that certain philosophical propositions—i.e., 1) uniformity of law and 2) uniformity of processes across time and space—must first be assumed before you can proceed as a scientist doing science. Gould summarized this view as follows:

> "The assumption of spatial and temporal invariance of natural laws is by no means unique to geology since it amounts to a warrant for inductive inference which, as Bacon showed nearly four hundred years ago, is the basic mode of reasoning in empirical science. Without assuming this spatial and temporal invariance, we have no basis for extrapolating from the known to the unknown and, therefore, no way of reaching general conclusions from a finite number of observations. (Since the assumption is itself vindicated by induction, it can in no way “prove” the validity of induction - an endeavor virtually abandoned after Hume demonstrated its futility two centuries ago)."[54]

Science policy

State policy has influenced the funding of public works and science for thousands of years, dating at least from the time of the Mohists, who inspired the study of logic during the period of the Hundred Schools of Thought, and the study of defensive fortifications during the Warring States Period in China. General levies of labor and grain were collected to fund great public works in China, including the accumulation of grain for distribution in times of famine,[55] for the building of levees to control flooding by the great rivers of China, for the building of canals and locks to connect rivers of China, some of which flowed in opposite directions to each other,[56] and for the building of bridges across these rivers. These projects required a civil service, the scholars, some of whom demonstrated great mastery of hydraulics.

In Italy, Galileo noted that individual taxation of minute amounts could fund large sums to the State, which could then fund his researches in the trajectory of cannonballs:

- "each individual soldier was being paid from coin collected by a general tax of pennies and farthings, while even a million of gold would not suffice to pay the entire army."[57]

In Great Britain, Lord Chancellor Sir Francis Bacon had a formative effect on science policy with his identification of "experiments of .. light, more penetrating into nature [than what others know]",[58] which today we call the crucial experiment. Governmental approval of the Royal Society recognized a scientific community which exists to this day. British prizes for research spurred the development of an accurate, portable chronometer, which directly enabled reliable navigation and sailing on the high seas, and also funded Babbage's computer.

The professionalization of science, begun in the nineteenth century, was partly enabled by the creation of scientific organizations such as the National Academy of Sciences, the Kaiser Wilhelm Institute, and State funding of universities of their respective nations. In the United States, a member of the National Academy of Sciences can sponsor a Direct Submission for publication in the *Proceedings of the National Academy of Sciences*.[59] *PNAS* serves as a channel to recognize research of importance to at least one member of the National Academy of Sciences.

Public policy can directly affect the funding of capital equipment, intellectual infrastructure for industrial research, by providing tax incentives to those organizations who fund research. Vannevar Bush, director of the office of scientific research and development for the U.S. government in July 1945, wrote

- "Science is a proper concern of government" [60]

Vannevar Bush directed the forerunner of the National Science Foundation, and his writings directly inspired researchers to invent the hyperlink and the computer mouse. The DARPA initiative to support computing was the impetus for the Internet Protocol stack. In the same way that scientific consortiums like CERN for high-energy physics have a commitment to public knowledge, access to this public knowledge in physics led directly to CERN's sponsorship of development of the World Wide Web and standard Internet access for all.

Pseudoscience, fringe science, and junk science

An area of study or speculation that masquerades as science in an attempt to claim a legitimacy that it would not otherwise be able to achieve is sometimes referred to as pseudoscience, fringe science, or "alternative science". Another term, junk science, is often used to describe scientific hypotheses or conclusions which, while perhaps legitimate in themselves, are believed to be used to support a position that is seen as not legitimately justified by the totality of evidence. Physicist Richard Feynman coined the term "cargo cult science" in reference to pursuits that have the formal trappings of science but lack "a principle of scientific thought that corresponds to a kind of utter honesty" that allows their results to be rigorously evaluated. Various types of commercial advertising, ranging from hype to fraud, may fall into these categories.

There also can be an element of political or ideological bias on all sides of such debates. Sometimes, research may be characterized as "bad science", research that is well-intentioned but is seen as incorrect, obsolete, incomplete, or over-simplified expositions of scientific ideas. The term "scientific misconduct" refers to situations such as where researchers have intentionally misrepresented their published data or have purposely given credit for a discovery to the wrong person.

Critiques

Philosophical critiques

Historian Jacques Barzun termed science "a faith as fanatical as any in history" and warned against the use of scientific thought to suppress considerations of meaning as integral to human existence.[61] Many recent thinkers, such as Carolyn Merchant, Theodor Adorno and E. F. Schumacher considered that the 17th century scientific revolution shifted science from a focus on understanding nature, or wisdom, to a focus on manipulating nature, i.e. power, and that science's emphasis on manipulating nature leads it inevitably to manipulate people, as well.[62] Science's focus on quantitative measures has led to critiques that it is unable to recognize important qualitative aspects of the world.[62]

Philosopher of science Paul K Feyerabend advanced the idea of epistemological anarchism, which holds that there are no useful and exception-free methodological rules governing the progress of science or the growth of knowledge, and that the idea that science can or should operate according to universal and fixed rules is unrealistic, pernicious and detrimental to science itself.[63] Feyerabend advocates treating science as an ideology alongside others such as religion, magic and mythology, and considers the dominance of science in society authoritarian and unjustified.[63] He also contended (along with Imre Lakatos) that the demarcation problem of distinguishing science from pseudoscience on objective grounds is not possible and thus fatal to the notion of science running according to fixed, universal rules.[63]

Feyerabend also criticized Science for not having evidence for its own philosophical precepts. Particularly the notion of Uniformity of Law and the Uniformity of Process across time and space. "We have to realize that a unified theory of the physical world simply does not exist" says Feyerabend, "We have theories that work in restricted regions, we have purely formal attempts to condense them into a single formula, we have lots of unfounded claims (such as the claim that all of chemistry can be reduced to physics), phenomena that do not fit into the accepted framework are suppressed; in physics, which many scientists regard as the one really basic science, we have now at least three different points of view...without a promise of conceptual (and not only formal) unification".[64]

Sociologist Stanley Aronowitz scrutinizes science for operating with the presumption that the only acceptable criticisms of science are those conducted within the methodological framework that science has set up for itself. That science insists that only those who have been inducted into its community, through means of training and credentials, are qualified to make these criticisms.[65] Aronowitz also alleges that while scientists consider it absurd that Fundamentalist Christianity uses biblical references to bolster their claim that the bible is true, scientists pull the same tactic by using the tools of science to settle disputes concerning its own validity.[66]

Psychologist Carl Jung believed that though science attempted to understand all of nature, the experimental method imposed artificial and conditional questions that evoke equally artificial answers. Jung encouraged, instead of these 'artificial' methods, empirically testing the world in a holistic manner.[67] David Parkin compared the epistemological stance of science to that of divination.[68] He suggested that, to the degree that divination is an epistemologically specific means of gaining insight into a given question, science itself can be considered a form of divination that is framed from a Western view of the nature (and thus possible applications) of knowledge.

Several academics have offered critiques concerning ethics in science. In *Science and Ethics*, for example, the philosopher Bernard Rollin examines the relevance of ethics to science, and argues in favor of making education in ethics part and parcel of scientific training.[69]

Media perspectives

The mass media face a number of pressures that can prevent them from accurately depicting competing scientific claims in terms of their credibility within the scientific community as a whole. Determining how much weight to give different sides in a scientific debate requires considerable expertise regarding the matter.[70] Few journalists have real scientific knowledge, and even beat reporters who know a great deal about certain scientific issues may know little about other ones they are suddenly asked to cover.[71] [72]

Politics

Many issues damage the relationship of science to the media and the use of science and scientific arguments by politicians. As a very broad generalisation, many politicians seek certainties and *facts* whilst scientists typically offer probabilities and caveats. However, politicians' ability to be heard in the mass media frequently distorts the scientific understanding by the public. Examples in Britain include the controversy over the MMR inoculation, and the 1988 forced resignation of a Government Minister, Edwina Currie for revealing the high probability that battery eggs were contaminated with *Salmonella*.[73]

See also

- Science wars
- Antiquarian science books

Notes

[1] "Online dictionary" (http://www.m-w.com/dictionary/science). Merriam-Webster. . Retrieved 2009-05-22. "knowledge or a system of knowledge covering general truths or the operation of general laws especially as obtained and tested through scientific method **. . .** such knowledge or such a system of knowledge concerned with the physical world and its phenomena"

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[4] Ludwik Fleck (1935), *Genesis and Development of a Scientific Fact* (http://books.google.com/books?id=0KAGUpaUaGYC&printsec=frontcover&dq=Ludwik+Fleck&source=bl&ots=LcJSSRN_ym&sig=TKrx9GLwFYRGlgIprAcdPFnhJIE&hl=en&ei=rbCWTPGpD8Oblgfmw9iiCg&sa=X&oi=book_result&ct=result&resnum=3&ved=0CB8Q6AEwAg#v=onepage&q&f=false) reminds us that before a specific fact 'existed', it had to be created as part of a social agreement within a community.

[5] Aristotle, ca. 4th century BCE 1139b "[[Nicomachean Ethics (http://www.perseus.tufts.edu/hopper/text?doc=Perseus:text:1999.01.0054:bekker page=1139b)] Book VI, and Metaphysics Book I:"]. 1139b. "In general the sign of knowledge or ignorance is the ability to teach, and for this reason we hold that art rather than experience is scientific knowledge (*epistemē*); *for the artists can teach, but the others cannot*." — Aristot. *Met.* 1.981b (http://www.perseus.tufts.edu/hopper/text?doc=Perseus:text:1999.01.0052:book=1:section=981b&highlight=artists,others)

[6] Consider, for example, Isaac Newton (1687) *Philosophiæ Naturalis Principia Mathematica*

[7] Max Born (1949, 1965) *Natural Philosophy of Cause and Chance* (http://www.archive.org/stream/naturalphilosoph032159mbp/naturalphilosoph032159mbp_djvu.txt) points out that all knowledge, including natural or social science, is also subjective. Page 162: "Thus it dawned upon me that fundamentally everything is subjective, everything without exception. That was a shock." See: intersubjective verifiability.

[8] See: Editorial Staff (March 7, 2008). "Scientific Method: Relationships among Scientific Paradigms" (http://www.seedmagazine.com/news/2007/03/scientific_method_relationship.php). Seed magazine. . Retrieved 2007-09-12.

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[10] Benedikt Löwe (2002) "The Formal Sciences: Their Scope, Their Foundations, and Their Unity" (http://www.jstor.org/pss/20117289)

[11] Peter Barrett (2004), *Science and Theology Since Copernicus: The Search for Understanding* (http://books.google.com/books?id=fwxViwX6KuMC&pg=PA14&dq&hl=en#v=onepage&q=&f=false), p. 14, Continuum International Publishing Group, ISBN 0-567-08969-X

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[13] "The Scientific Revolution" (http://www.wsu.edu/~dee/ENLIGHT/SCIREV.HTM). Washington State University

[14] It is the nominal form of the verb *scire*, "to know". The Proto-Indo-European (PIE) root that yields *scire* is **skei-*, meaning to "cut, separate, or discern".

[15] Etymology of "science" at Etymology Online (http://www.etymonline.com/index.php?search=science&searchmode=none). See also details of the PIE root at American Heritage Dictionary of the English Language*, 4th edition, 2000.* (http://www.bartleby.com/61/roots/IE464.html).

[16] "... [A] man knows a thing scientifically when he possesses a conviction arrived at in a certain way, and when the first principles on which that conviction rests are known to him with certainty—for unless he is more certain of his first principles than of the conclusion drawn from them he will only possess the knowledge in question accidentally." — Aristotle, *Nicomachean Ethics* **6** (H. Rackham, ed.) Aristot. Nic. Eth. 1139b (http://www.perseus.tufts.edu/hopper/text?doc=Perseus:text:1999.01.0054:bekker page=1139b)

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[25] Stanovich, 2007, pg 106-110

[26] The models need not be completely abstract: when modeling, the problems can be simplified — strings joining masses may be modeled as unstretchable, as in a metallic wire, or perhaps be modeled with noticeable mass, as in a dog chain. Once a mathematical solution is known, it can be re-used elsewhere in science.

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[33] Stanovich 2007 pg 119-138

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[39] Peirce (1868), "Some Consequences of Four Incapacities", *Journal of Speculative Philosophy* v. 2, n. 3, pp. 140-57, see p. 141 (http://books.google.com/books?id=YHkqP2JHJ_IC&pg=RA1-PA141). Reprinted in *Collected Papers*, v. 5, paragraphs 264-317, *Writings* v. 2, pp. 211-42, *Essential Peirce* v. 1, pp. 28-55, and elsewhere.

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External links

Publications

- "*GCSE Science textbook*". Wikibooks.org

News

- Nature News (http://www.nature.com/news/). Science news by the journal *Nature*
- New Scientist (http://www.newscientist.com/). An weekly magazine published by Reed Business Information
- ScienceDaily (http://www.sciencedaily.com/)
- Science Newsline (http://www.sciencenewsline.com/)
- Sciencia (http://sciencia.org/)
- Discover Magazine (http://www.discovermagazine.com/)
- Irish Science News (http://www.science.ie/) from Discover Science & Engineering
- Science Stage (http://sciencestage.com/) Scientific Videoportal and Community

Resources

- Euroscience (http://www.euroscience.org/):
  - Euroscience Open Forum (http://www.euroscience.org/esof.html) (ESOF)
- Science Council (http://www.sciencecouncil.org/DefiningScience.php)
- Science Development in the *Latin American docta* (http://www.en.argentina.ar/_en/science-and-education/)
- Classification of the Sciences (http://xtf.lib.virginia.edu/xtf/view?docId=DicHist/uvaBook/tei/DicHist1.xml;chunk.id=dv1-57;toc.depth=1;toc.id=dv1-57;brand=default) in *Dictionary of the History of Ideas*.

(Dictionary's new electronic format is badly botched, entries after "Design" are inaccessible. *Internet Archive* old version (http://web.archive.org/web/20080619205103/http://etext.lib.virginia.edu/cgi-local/DHI/dhi.cgi?id=dv1-57)).

- "Nature of Science" (http://evolution.berkeley.edu/evosite/nature/index.shtml) University of California Museum of Paleontology
- United States Science Initiative (http://www.science.gov). Selected science information provided by U.S. Government agencies, including research and development results.

Scientific method

Scientific method refers to a body of techniques for investigating phenomena, acquiring new knowledge, or correcting and integrating previous knowledge.[1] To be termed scientific, a method of inquiry must be based on gathering observable, empirical and measurable evidence subject to specific principles of reasoning.[2] A scientific method consists of the collection of data through observation and experimentation, and the formulation and testing of hypotheses.[3]

Although procedures vary from one field of inquiry to another, identifiable features distinguish scientific inquiry from other methods of obtaining knowledge. Scientific researchers propose hypotheses as explanations of phenomena, and design experimental studies to test these hypotheses. These steps must be repeatable, to predict future results. Theories that encompass wider domains of inquiry may bind many independently derived hypotheses together in a coherent, supportive structure. Theories, in turn, may help form new hypotheses or place groups of hypotheses into context.

Scientific inquiry is generally intended to be as objective as possible, to reduce biased interpretations of results. Another basic expectation is to document, archive and share all data and methodology so they are available for careful scrutiny by other scientists, giving them the opportunity to verify results by attempting to reproduce them. This practice, called *full disclosure*, also allows statistical measures of the reliability of these data to be established.

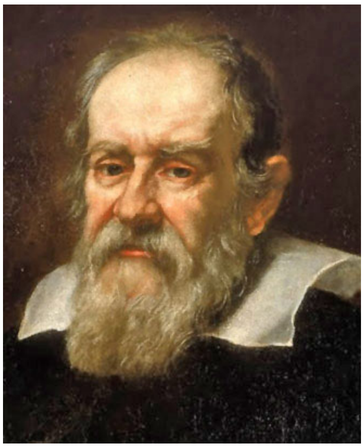
Introduction to scientific method

Scientific method follows the laws of logic first defined by Greek philosopher Aristotle (384–322 BCE).[6] Aristotle perfected observation and classification based on analysis, and set the stage for theory based on observation, which remains today's standard for scientific thought.[7] [8]

Ibn al-Haytham (Alhazen), 965–1039, Basra.

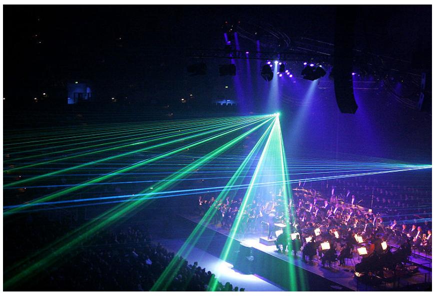
Since Ibn al-Haytham (Alhazen, 965–1039), one of the key figures in the development of scientific method, the emphasis has been on seeking truth:

> Truth is sought for its own sake. And those who are engaged upon the quest for anything for its own sake are not interested in other things. Finding the truth is difficult, and the road to it is rough.[9]



"Modern science owes its origins and present flourishing state to a new scientific method which was fashioned almost entirely by Galileo Galilei (1564-1642)" —Morris Kline[4]

Johannes Kepler (1571–1630). "Kepler shows his keen logical sense in detailing the whole process by which he finally arrived at the true orbit. This is the greatest piece of Retroductive reasoning ever performed." —C. S. Peirce, circa 1896, on Kepler's reasoning through explanatory hypotheses[5]



"Light travels through transparent bodies in straight lines only" — Alhazen in *Book of Optics* (1021).

> How does light travel through transparent bodies? Light travels through transparent bodies in straight lines only.... We have explained this exhaustively in our *Book of Optics*. But let us now mention something to prove this convincingly: the fact that light travels in straight lines is clearly observed in the lights which enter into dark rooms through holes.... [T]he entering light will be clearly observable in the dust which fills the air.[10]

The conjecture that "light travels through transparent bodies in straight lines only" was corroborated by Alhazen only after years of effort. His demonstration of the conjecture was to place a straight stick or a taut thread next to the light beam,[11] to prove that light travels in a straight line.

Scientific methodology has been practiced in some form for at least one thousand years. There are difficulties in a formulaic statement of method, however. As William Whewell (1794–1866) noted in his *History of Inductive Science* (1837) and in *Philosophy of Inductive Science* (1840), "invention, sagacity, genius" are required at every step in scientific method. It is not enough to base scientific method on experience alone;[12] multiple steps are needed in scientific method, ranging from our experience to our imagination, back and forth.

In the twentieth century, a hypothetico-deductive model for scientific method was formulated (for a more formal discussion, see below):

> ***1***. Use your experience: Consider the problem and try to make sense of it. Look for previous explanations. If this is a new problem to you, then move to step ***2***.
>
> ***2***. Form a conjecture: When nothing else is yet known, try to state an explanation, to someone else, or to your notebook.
>
> ***3***. Deduce a prediction from that explanation: If you assume ***2*** is true, what consequences follow?
>
> ***4***. Test: Look for the opposite of each consequence in order to disprove ***2***. It is a logical error to seek ***3*** directly as proof of ***2***. This error is called *affirming the consequent*.[13]

This model underlies the scientific revolution. One thousand years ago, Alhazen demonstrated the importance of steps ***1*** and ***4***. Galileo (1638) also showed the importance of step ***4*** (also called Experiment) in *Two New Sciences*.[14] One possible sequence in this model would be ***1***, ***2***, ***3***, ***4***. If the outcome of ***4*** holds, and ***3*** is not yet disproven, you may continue with ***3***, ***4***, ***1***, and so forth; but if the outcome of ***4*** shows ***3*** to be false, you will have go back to ***2*** and try to invent a ***new 2***, deduce a ***new 3***, look for ***4***, and so forth.

Note that this method can never absolutely **verify** (prove the truth of) ***2***. It can only **falsify** ***2***.[15] (This is what Einstein meant when he said, "No amount of experimentation can ever prove me right; a single experiment can prove me wrong."[16]) However, as pointed out by Carl Hempel (1905–1997) this simple view of scientific method is incomplete; the formulation of the conjecture might itself be the result of inductive reasoning. Thus the likelihood of the prior observation being true is statistical in nature [17] and would strictly require a Bayesian analysis. To overcome this uncertainty, experimental scientists must formulate a *crucial experiment*,[18] in order for it to corroborate a more likely hypothesis.

In the twentieth century, Ludwik Fleck (1896–1961) and others argued that scientists need to consider their experiences more carefully, because their experience may be biased, and that they need to be more exact when describing their experiences.[19]

DNA example

The Keystones of Science project, sponsored by the journal *Science*, has selected a number of scientific articles from that journal and annotated them, illustrating how different parts of each article embody scientific method. Here [20] is an annotated example of this scientific method example titled "Microbial Genes in the Human Genome: Lateral Transfer or Gene Loss?".

Four basic elements of scientific method are illustrated below, by example from the discovery of the structure of DNA:

- *DNA-characterizations*: in this case, although the significance of the gene had been established, the mechanism was unclear to anyone, as of 1950.
- *DNA-hypotheses*: Crick and Watson hypothesized that the gene had a physical basis–it was helical.[21]
- *DNA-predictions*: from earlier work on tobacco mosaic virus,[22] Watson was aware of the significance of Crick's formulation of the transform of a helix.[23] Thus he was primed for the significance of the X-shape in photo 51.
- *DNA-experiments*: Watson sees photo 51.[24]

The examples are continued in "Evaluations and iterations" with *DNA-iterations*.[25]

Truth and belief

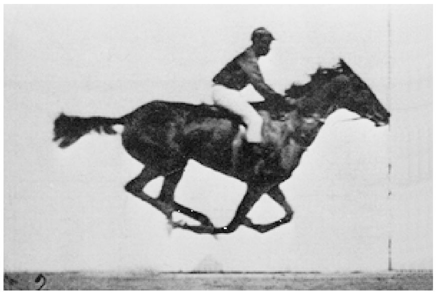
In the same way that Alhazen sought truth during his pioneering studies in optics 1000 years ago, arriving at the truth is the goal of a scientific inquiry.[26]

Beliefs and biases

Belief can alter observations; the human confirmation bias is a heuristic that leads a person with a particular belief to see things as reinforcing their belief, even if another observer would disagree. Researchers have often admitted that the first observations were a little imprecise, whereas the second and third were "adjusted to the facts". Eventually, factors such as openness to experience, self-esteem, time, and comfort can produce a readiness for new perception.[27]

Flying gallop falsified; see image below.

Needham's *Science and Civilization in China* uses the 'flying gallop' image as an example of observation bias:[28] In these types of images, the legs of a galloping horse are depicted as splayed, while the stop-action pictures of a horse's gallop by Eadweard Muybridge show otherwise. In a gallop, at the moment that no hoof is touching the ground, a horse's legs are gathered together and are not splayed. Earlier paintings depict the incorrect flying gallop observation.



Eadweard Muybridge's studies of a horse galloping

This image demonstrates Ludwik Fleck's caution that people observe what they expect to observe, until shown otherwise; their beliefs will affect their observations (and, therefore, their subsequent actions, in a self-fulfilling prophecy). It is for this reason that scientific methodology prefers that hypotheses be tested in controlled conditions which can be reproduced by multiple researchers. With the scientific community's pursuit of experimental control and reproducibility, cognitive biases are diminished.

Certainty and myth

A scientific theory hinges on empirical findings, and remains subject to falsification if new evidence is presented. That is, no theory is ever considered certain. Theories very rarely result in vast changes in human understanding. Knowledge in science is gained by a gradual synthesis of information from different experiments, by various researchers, across different domains of science.[29] Theories vary in the extent to which they have been tested and retained, as well as their acceptance in the scientific community.

In contrast, a myth may enjoy uncritical acceptance by members of a certain group.[30] The difference between a theory and a myth reflects a preference for *a posteriori* versus *a priori* knowledge. That is, theories become accepted by a scientific community as evidence for the theory is presented, and as presumptions that are inconsistent with the evidence are falsified.

Elements of scientific method

There are different ways of outlining the basic method used for scientific inquiry. The scientific community and philosophers of science generally agree on the following classification of method components. These methodological elements and organization of procedures tend to be more characteristic of natural sciences than social sciences. Nonetheless, the cycle of formulating hypotheses, testing and analyzing the results, and formulating new hypotheses, will resemble the cycle described below.

> Four essential elements[31] [32] [33] of a scientific method[34] are iterations,[35] [36] recursions,[37] interleavings, or orderings of the following:

- Characterizations (observations,[38] definitions, and measurements of the subject of inquiry)
- Hypotheses[39] [40] (theoretical, hypothetical explanations of observations and measurements of the subject)[41]
- Predictions (reasoning including logical deduction[42] from the hypothesis or theory)
- Experiments[43] (tests of all of the above)

Each element of a scientific method is subject to peer review for possible mistakes. These activities do not describe all that scientists do (see below) but apply mostly to experimental sciences (e.g., physics, chemistry, and biology). The elements above are often taught in the educational system.[44]

Scientific method is not a recipe: it requires intelligence, imagination, and creativity.[45] In this sense, it is not a mindless set of standards and procedures to follow, but is rather an ongoing cycle, constantly developing more useful, accurate and comprehensive models and methods. For example, when Einstein developed the Special and General Theories of Relativity, he did not in any way refute or discount Newton's *Principia*. On the contrary, if the astronomically large, the vanishingly small, and the extremely fast are reduced out from Einstein's theories — all phenomena that Newton could not have observed — Newton's equations remain. Einstein's theories are expansions and refinements of Newton's theories and, thus, increase our confidence in Newton's work.

A linearized, pragmatic scheme of the four points above is sometimes offered as a guideline for proceeding:[46]

1. Define the question
2. Gather information and resources (observe)
3. Form hypothesis
4. Perform experiment and collect data
5. Analyze data
6. Interpret data and draw conclusions that serve as a starting point for new hypothesis
7. Publish results
8. Retest (frequently done by other scientists)

The iterative cycle inherent in this step-by-step methodology goes from point 3 to 6 back to 3 again.

While this schema outlines a typical hypothesis/testing method,[47] it should also be noted that a number of philosophers, historians and sociologists of science (perhaps most notably Paul Feyerabend) claim that such descriptions of scientific method have little relation to the ways science is actually practiced.

The "operational" paradigm combines the concepts of operational definition, instrumentalism, and utility:

The essential elements of a scientific method are operations, observations, models, and a utility function for evaluating models.[48]

- Operation - Some action done to the system being investigated
- Observation - What happens when the operation is done to the system
- Model - A fact, hypothesis, theory, or the phenomenon itself at a certain moment
- Utility Function - A measure of the usefulness of the model to explain, predict, and control, and of the cost of use of it. One of the elements of any scientific utility function is the refutability of the model. Another is its simplicity, on the Principle of Parsimony also known as Occam's Razor.

Characterizations

Scientific method depends upon increasingly sophisticated characterizations of the subjects of investigation. (The *subjects* can also be called *unsolved problems* or the *unknowns*.) For example, Benjamin Franklin correctly characterized St. Elmo's fire as electrical in nature, but it has taken a long series of experiments and theory to establish this. While seeking the pertinent properties of the subjects, this careful thought may also entail some definitions and observations; the observations often demand careful measurements and/or counting.

The systematic, careful collection of measurements or counts of relevant quantities is often the critical difference between pseudo-sciences, such as alchemy, and a science, such as chemistry or biology. Scientific measurements taken are usually tabulated, graphed, or mapped, and statistical manipulations, such as correlation and regression, performed on them. The measurements might be made in a controlled setting, such as a laboratory, or made on more or less inaccessible or unmanipulatable objects such as stars or human populations. The measurements often require specialized scientific instruments such as thermometers, spectroscopes, or voltmeters, and the progress of a scientific field is usually intimately tied to their invention and development.

"I am not accustomed to saying anything with certainty after only one or two observations."—Andreas Vesalius (1546) [49]

Uncertainty

Measurements in scientific work are also usually accompanied by estimates of their uncertainty. The uncertainty is often estimated by making repeated measurements of the desired quantity. Uncertainties may also be calculated by consideration of the uncertainties of the individual underlying quantities that are used. Counts of things, such as the number of people in a nation at a particular time, may also have an uncertainty due to limitations of the method used. Counts may only represent a sample of desired quantities, with an uncertainty that depends upon the sampling method used and the number of samples taken.

Definition

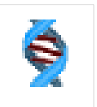
Measurements demand the use of *operational definitions* of relevant quantities. That is, a scientific quantity is described or defined by how it is measured, as opposed to some more vague, inexact or "idealized" definition. For example, electrical current, measured in amperes, may be operationally defined in terms of the mass of silver deposited in a certain time on an electrode in an electrochemical device that is described in some detail. The operational definition of a thing often relies on comparisons with standards: the operational definition of "mass" ultimately relies on the use of an artifact, such as a certain kilogram of platinum-iridium kept in a laboratory in France.

The scientific definition of a term sometimes differs substantially from its natural language usage. For example, mass and weight overlap in meaning in common discourse, but have distinct meanings in mechanics. Scientific quantities are often characterized by their units of measure which can later be described in terms of conventional physical units when communicating the work.

New theories sometimes arise upon realizing that certain terms had not previously been sufficiently clearly defined. For example, Albert Einstein's first paper on relativity begins by defining simultaneity and the means for determining length. These ideas were skipped over by Isaac Newton with, "*I do not define time, space, place and motion, as being well known to all.*" Einstein's paper then demonstrates that they (viz., absolute time and length independent of motion) were approximations. Francis Crick cautions us that when characterizing a subject, however, it can be premature to define something when it remains ill-understood.[50] In Crick's study of consciousness, he actually found it easier to study awareness in the visual system, rather than to study free will, for example. His cautionary example was the gene; the gene was much more poorly understood before Watson and Crick's pioneering discovery of the structure of DNA; it would have been counterproductive to spend much time on the definition of the gene, before them.

Example of characterizations

DNA-characterizations



The history of the discovery of the structure of DNA is a classic example of the elements of scientific method: in 1950 it was known that genetic inheritance had a mathematical description, starting with the studies of Gregor Mendel. But the mechanism of the gene was unclear. Researchers in Bragg's laboratory at Cambridge University made X-ray diffraction pictures of various molecules, starting with crystals of salt, and proceeding to more complicated substances. Using clues which were painstakingly assembled over the course of decades, beginning with its chemical composition, it was determined that it should be possible to characterize the physical structure of DNA, and the X-ray images would be the vehicle. *..2. DNA-hypotheses*

Precession of Mercury

The characterization element can require extended and extensive study, even centuries. It took thousands of years of measurements, from the Chaldean, Indian, Persian, Greek, Arabic and European astronomers, to record the motion of planet Earth. Newton was able to condense these measurements into consequences of his laws of motion. But the perihelion of the planet Mercury's orbit exhibits a precession that is not fully explained by Newton's laws of motion (see diagram to the right). The observed difference for Mercury's precession between Newtonian theory and relativistic theory (approximately 43 arc-seconds per century), was one of the things that occurred to Einstein as a possible early test of his theory of General Relativity.

Precession of the perihelion (exaggerated)

Hypothesis development

A hypothesis is a suggested explanation of a phenomenon, or alternately a reasoned proposal suggesting a possible correlation between or among a set of phenomena.

Normally hypotheses have the form of a mathematical model. Sometimes, but not always, they can also be formulated as existential statements, stating that some particular instance of the phenomenon being studied has some characteristic and causal explanations, which have the general form of universal statements, stating that every instance of the phenomenon has a particular characteristic.

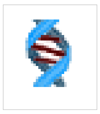
Scientists are free to use whatever resources they have — their own creativity, ideas from other fields, induction, Bayesian inference, and so on — to imagine possible explanations for a phenomenon under study. Charles Sanders Peirce, borrowing a page from Aristotle (*Prior Analytics*, 2.25) described the incipient stages of inquiry, instigated by the "irritation of doubt" to venture a plausible guess, as *abductive reasoning*. The history of science is filled with stories of scientists claiming a "flash of inspiration", or a hunch, which then motivated them to look for evidence to support or refute their idea. Michael Polanyi made such creativity the centerpiece of his discussion of methodology.

William Glen observes that

> the success of a hypothesis, or its service to science, lies not simply in its perceived "truth", or power to displace, subsume or reduce a predecessor idea, but perhaps more in its ability to stimulate the research that will illuminate … bald suppositions and areas of vagueness.[51]

In general scientists tend to look for theories that are "elegant" or "beautiful". In contrast to the usual English use of these terms, they here refer to a theory in accordance with the known facts, which is nevertheless relatively simple and easy to handle. Occam's Razor serves as a rule of thumb for making these determinations.

DNA-hypotheses



Linus Pauling proposed that DNA might be a triple helix.[52] This hypothesis was also considered by Francis Crick and James D. Watson but discarded. When Watson and Crick learned of Pauling's hypothesis, they understood from existing data that Pauling was wrong[53] and that Pauling would soon admit his difficulties with that structure. So, the race was on to figure out the correct structure (except that Pauling did not realize at the time that he was in a race—see section on "DNA-predictions" below)

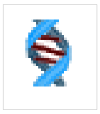
Predictions from the hypothesis

Any useful hypothesis will enable predictions, by reasoning including deductive reasoning. It might predict the outcome of an experiment in a laboratory setting or the observation of a phenomenon in nature. The prediction can also be statistical and only talk about probabilities.

It is essential that the outcome be currently unknown. Only in this case does the eventuation increase the probability that the hypothesis be true. If the outcome is already known, it's called a consequence and should have already been considered while formulating the hypothesis.

If the predictions are not accessible by observation or experience, the hypothesis is not yet useful for the method, and must wait for others who might come afterward, and perhaps rekindle its line of reasoning. For example, a new technology or theory might make the necessary experiments feasible.

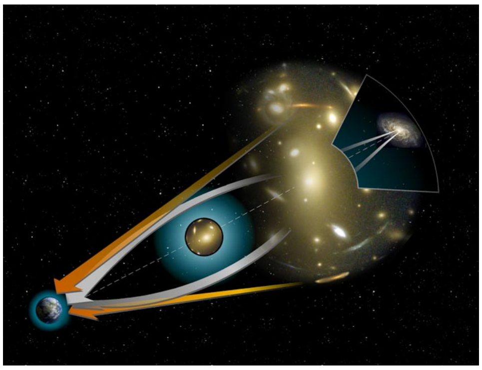
DNA-predictions



James D. Watson, Francis Crick, and others hypothesized that DNA had a helical structure. This implied that DNA's X-ray diffraction pattern would be 'x shaped'.[54] [55] This prediction followed from the work of Cochran, Crick and Vand[23] (and independently by Stokes). The Cochran-Crick-Vand-Stokes theorem provided a mathematical explanation for the empirical observation that diffraction from helical structures produces x shaped patterns.

Also in their first paper, Watson and Crick predicted that the double helix structure provided a simple mechanism for DNA replication, writing "It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material". *..4. DNA-experiments*

General relativity



Einstein's prediction (1907): Light bends in a gravitational field

Einstein's theory of General Relativity makes several specific predictions about the observable structure of space-time, such as a prediction that light bends in a gravitational field and that the amount of bending depends in a precise way on the strength of that gravitational field. Arthur Eddington's observations made during a 1919 solar eclipse supported General Relativity rather than Newtonian gravitation.[56]

Experiments

Once predictions are made, they can be tested by experiments. If test results contradict predictions, then the hypotheses are called into question and explanations may be sought. Sometimes experiments are conducted incorrectly and are at fault. If the results confirm the predictions, then the hypotheses are considered likely to be correct but might still be wrong and are subject to further testing. The experimental control is a technique for dealing with observational error. This technique uses the contrast between multiple samples (or observations) under differing conditions, to see what varies or what remains the same. We vary the conditions for each measurement, to help isolate what has changed. Mill's canons can then help us figure out what the important factor is.[57] Factor analysis is one technique for discovering the important factor in an effect.

Depending on the predictions, the experiments can have different shapes. It could be a classical experiment in a laboratory setting, a double-blind study or an archaeological excavation. Even taking a plane from New York to Paris is an experiment which tests the aerodynamical hypotheses used for constructing the plane.

Scientists assume an attitude of openness and accountability on the part of those conducting an experiment. Detailed record keeping is essential, to aid in recording and reporting on the experimental results, and providing evidence of the effectiveness and integrity of the procedure. They will also assist in reproducing the experimental results. Traces of this tradition can be seen in the work of Hipparchus (190-120 BCE), when determining a value for the precession of the Earth, while controlled experiments can be seen in the works of Muslim scientists such as Jābir ibn Hayyān (721-815 CE), al-Battani (853–929) and Alhacen (965-1039).

DNA-experiments

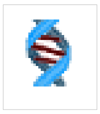
Watson and Crick showed an initial (and incorrect) proposal for the structure of DNA to a team from Kings College - Rosalind Franklin, Maurice Wilkins, and Raymond Gosling. Franklin immediately spotted the flaws which concerned the water content. Later Watson saw Franklin's detailed X-ray diffraction images which showed an X-shape [58] and confirmed that the structure was helical.[24] [59] This rekindled Watson and Crick's model building and led to the correct structure. *..1. DNA-characterizations*

Evaluation and improvement

The scientific process is iterative. At any stage it is possible to refine its accuracy and precision, so that some consideration will lead the scientist to repeat an earlier part of the process. Failure to develop an interesting hypothesis may lead a scientist to re-define the subject they are considering. Failure of a hypothesis to produce interesting and testable predictions may lead to reconsideration of the hypothesis or of the definition of the subject. Failure of the experiment to produce interesting results may lead the scientist to reconsidering the experimental method, the hypothesis or the definition of the subject.

Other scientists may start their own research and enter the process at any stage. They might adopt the characterization and formulate their own hypothesis, or they might adopt the hypothesis and deduce their own predictions. Often the experiment is not done by the person who made the prediction and the characterization is based on experiments done by someone else. Published results of experiments can also serve as a hypothesis predicting their own reproducibility.

DNA-iterations



After considerable fruitless experimentation, being discouraged by their superior from continuing, and numerous false starts, Watson and Crick were able to infer the essential structure of DNA by concrete modeling of the physical shapes of the nucleotides which comprise it.[25] [60] They were guided by the bond lengths which had been deduced by Linus Pauling and by Rosalind Franklin's X-ray diffraction images. ..*DNA Example*

Confirmation

Science is a social enterprise, and scientific work tends to be accepted by the community when it has been confirmed. Crucially, experimental and theoretical results must be reproduced by others within the scientific community. Researchers have given their lives for this vision; Georg Wilhelm Richmann was killed by ball lightning (1753) when attempting to replicate the 1752 kite-flying experiment of Benjamin Franklin.[61]

To protect against bad science and fraudulent data, governmental research-granting agencies such as the National Science Foundation, and science journals including *Nature* and *Science*, have a policy that researchers must archive their data and methods so other researchers can access it, test the data and methods and build on the research that has gone before. Scientific data archiving can be done at a number of national archives in the U.S. or in the World Data Center.

Models of scientific inquiry

Classical model

The classical model of scientific inquiry derives from Aristotle,[62] who distinguished the forms of approximate and exact reasoning, set out the threefold scheme of abductive, deductive, and inductive inference, and also treated the compound forms such as reasoning by analogy.

Pragmatic model

In 1877,[63] Charles Sanders Peirce (pronounced /ˈpɜrs/ *purse*) (1839–1914) characterized inquiry in general not as the pursuit of truth *per se* but as the struggle to move from irritating, inhibitory doubts born of surprises, disagreements, and the like, and to reach a secure belief, belief being that on which one is prepared to act. He framed scientific inquiry as part of a broader spectrum and as spurred, like inquiry generally, by actual doubt, not mere verbal or hyperbolic doubt, which he held to be fruitless.[64] He outlined four methods of settling opinion, ordered from least to most successful:

1. The method of tenacity (policy of sticking to initial belief) — which brings comforts and decisiveness but leads to trying to ignore contrary information and others' views as if truth were intrinsically private, not public. It goes against the social impulse and easily falters since one may well notice when another's opinion is as good as one's own initial opinion. Its successes can shine but tend to be transitory.
2. The method of authority — which overcomes disagreements but sometimes brutally. Its successes can be majestic and long-lived, but it cannot operate thoroughly enough to suppress doubts indefinitely, especially when people learn of other societies present and past.
3. The method of congruity or the *a priori* or the dilettante or "what is agreeable to reason" — which promotes conformity less brutally but depends on taste and fashion in paradigms and can go in circles over time, along with barren disputation. It is more intellectual and respectable but, like the first two methods, sustains capricious and

accidental beliefs, destining some minds to doubts.

4. The scientific method — the method wherein inquiry regards itself as fallible and purposely tests itself and criticizes, corrects, and improves itself.

Peirce held that slow, stumbling ratiocination can be dangerously inferior to instinct and traditional sentiment in practical matters, and that the scientific method is best suited to theoretical research,[65] which in turn should not be trammeled by the other methods and practical ends; reason's "first rule" is that, in order to learn, one must desire to learn and, as a corollary, must not block the way of inquiry.[66] The scientific method excels the others by being deliberately designed to arrive — eventually — at the most secure beliefs, upon which the most successful practices can be based. Starting from the idea that people seek not truth *per se* but instead to subdue irritating, inhibitory doubt, Peirce showed how, through the struggle, some can come to submit to truth for the sake of belief's integrity, seek as truth the guidance of potential practice correctly to its given goal, and wed themselves to the scientific method.[63] [67]

For Peirce, rational inquiry implies presuppositions about truth and the real; to reason is to presuppose (and at least to hope), as a principle of the reasoner's self-regulation, that the real is discoverable and independent of our vagaries of opinion. In that vein he defined truth as the correspondence of a sign (in particular, a proposition) to its object and, pragmatically, not as actual consensus of some definite, finite community (such that to inquire would be to poll the experts), but instead as that final opinion which all investigators *would* reach sooner or later but still inevitably, if they were to push investigation far enough, even when they start from different points.[68] In tandem he defined the real as a true sign's object (be that object a possibility or quality, or an actuality or brute fact, or a necessity or norm or law), which is what it is independently of any finite community's opinion and, pragmatically, depends only on the final opinion destined in a sufficient investigation. That is a destination as far, or near, as the truth itself to you or me or the given finite community. Thus his theory of inquiry boils down to "Do the science." Those conceptions of truth and the real involve the idea of a community both without definite limits (and thus potentially self-correcting as far as needed) and capable of definite increase of knowledge.[69] As inference, "logic is rooted in the social principle" since it depends on a standpoint that is, in a sense, unlimited.[70]

Paying special attention to the generation of explanations, Peirce outlined scientific method as a coordination of three kinds of inference in a purposeful cycle aimed at settling doubts, as follows:[71]

1. **Abduction** (or retroduction). Guessing, inference to explanatory hypotheses for selection of those best worth trying. From abduction, Peirce distinguishes induction as inferring, on the basis of tests, the proportion of truth in the hypothesis. Every inquiry, whether into ideas, brute facts, or norms and laws, arises from surprising observations in one or more of those realms (and for example at any stage of an inquiry already underway). All explanatory content of theories comes from abduction, which guesses a new or outside idea to account in a simple, economic way for a phenomenon that seems surprising or complicative. Oftenest, even a well-prepared mind guesses wrong. But the modicum of success of our guesses far exceeds that of sheer luck and seems born of attunement to nature by instincts developed or inherent, especially insofar as best guesses are optimally plausible and simple in the sense, said Peirce, of "facile and natural", as by Galileo's natural light of reason and as distinct from "logical simplicity". Abduction is the most fertile but least secure mode of inference. Its general rationale is inductive: it succeeds often enough and, without it, there is no hope of sufficiently expediting inquiry (often multi-generational) toward new truths.[72] Coordinative method leads from abducing a plausible hypothesis to judging it for its testability[73] and for how its trial would economize inquiry itself.[74] Peirce calls his pragmatism "the logic of abduction".[75] His pragmatic maxim is: "Consider what effects that might conceivably have practical bearings you conceive the objects of your conception to have. Then, your conception of those effects is the whole of your conception of the object".[68] His pragmatism is a method of reducing conceptual confusions fruitfully by equating the meaning of any conception with the conceivable practical implications of its object's conceived effects — a method of experimentational mental reflection hospitable to forming hypotheses and conducive to testing them. It points to efficiency. The hypothesis, being insecure, needs to have practical implications leading at least to mental tests and, in science, lending

themselves to scientific tests. A simple but unlikely guess, if uncostly to test for falsity, may belong first in line for testing. A guess's objective probability recommends it as worth testing, while subjective likelihood can be misleading. Guesses can be chosen for trial strategically, for which Peirce gave as example the game of Twenty Questions.[76] One can hope to discover only that which time would reveal through a learner's sufficient experience anyway, so the point is to expedite it; the economy of research is what demands the "leap" of abduction and governs its art.[74]

2. **Deduction**. Analysis of hypothesis and deduction of its consequences (for induction to test so as to evaluate the hypothesis). Two stages:

i. Explication. Logical analysis of the hypothesis in order to render its parts as clear as possible.

ii. Demonstration (or deductive argumentation). Deduction of hypothesis's consequence. Corollarial or, if needed, Theorematic.

3. **Induction**. The long-run validity of the rule of induction is deducible from the principle (presuppositional to reasoning in general[68]) that the real is only the object of the final opinion to which adequate investigation would lead[77] Induction involving ongoing tests or observations follows a method which, sufficiently persisted in, will diminish its error below any predesignate degree[71] and, if there were something to which such a process would *never* lead, then that thing would not be real. Three stages:

i. Classification. Classing objects of experience under general ideas.

ii. Probation (or direct Inductive Argumentation): Crude (the enumeration of instances) or Gradual (new estimate of proportion of truth in the hypothesis after each test). Gradual Induction is Qualitative or Quantitative; if Quantitative, then dependent on measurements, or on statistics, or on countings.

iii. Sentential Induction. "...which, by Inductive reasonings, appraises the different Probations singly, then their combinations, then makes self-appraisal of these very appraisals themselves, and passes final judgment on the whole result".[71]

Computational approaches

Many subspecialties of applied logic and computer science, such as artificial intelligence, machine learning, computational learning theory, inferential statistics, and knowledge representation, are concerned with setting out computational, logical, and statistical frameworks for the various types of inference involved in scientific inquiry. In particular, they contribute hypothesis formation, logical deduction, and empirical testing. Some of these applications draw on measures of complexity from algorithmic information theory to guide the making of predictions from prior distributions of experience, for example, see the complexity measure called the *speed prior* from which a computable strategy for optimal inductive reasoning can be derived.

Communication and community

Frequently a scientific method is employed not only by a single person, but also by several people cooperating directly or indirectly. Such cooperation can be regarded as one of the defining elements of a scientific community. Various techniques have been developed to ensure the integrity of that scientific method within such an environment.

Peer review evaluation

Scientific journals use a process of *peer review*, in which scientists' manuscripts are submitted by editors of scientific journals to (usually one to three) fellow (usually anonymous) scientists familiar with the field for evaluation. The referees may or may not recommend publication, publication with suggested modifications, or, sometimes, publication in another journal. This serves to keep the scientific literature free of unscientific or pseudoscientific work, to help cut down on obvious errors, and generally otherwise to improve the quality of the material.

Documentation and replication

Sometimes experimenters may make systematic errors during their experiments, unconsciously veer from a scientific method (Pathological science) for various reasons, or, in rare cases, deliberately report false results. Consequently, it is a common practice for other scientists to attempt to repeat the experiments in order to duplicate the results, thus further validating the hypothesis.

Archiving

As a result, researchers are expected to practice scientific data archiving in compliance with the policies of government funding agencies and scientific journals. Detailed records of their experimental procedures, raw data, statistical analyses and source code are preserved in order to provide evidence of the effectiveness and integrity of the procedure and assist in reproduction. These procedural records may also assist in the conception of new experiments to test the hypothesis, and may prove useful to engineers who might examine the potential practical applications of a discovery.

Data sharing

When additional information is needed before a study can be reproduced, the author of the study is expected to provide it promptly. If the author refuses to share data, appeals can be made to the journal editors who published the study or to the institution which funded the research.

Limitations

Since it is impossible for a scientist to record *everything* that took place in an experiment, facts selected for their apparent relevance are reported. This may lead, unavoidably, to problems later if some supposedly irrelevant feature is questioned. For example, Heinrich Hertz did not report the size of the room used to test Maxwell's equations, which later turned out to account for a small deviation in the results. The problem is that parts of the theory itself need to be assumed in order to select and report the experimental conditions. The observations are hence sometimes described as being 'theory-laden'.

Dimensions of practice

The primary constraints on contemporary western science are:

- Publication, i.e. Peer review
- Resources (mostly funding)

It has not always been like this: in the old days of the "gentleman scientist" funding (and to a lesser extent publication) were far weaker constraints.

Both of these constraints indirectly bring in a scientific method — work that too obviously violates the constraints will be difficult to publish and difficult to get funded. Journals do not require submitted papers to conform to anything more specific than "good scientific practice" and this is mostly enforced by peer review. Originality, importance and interest are more important - see for example the author guidelines [78] for *Nature*.

Criticisms (see Critical theory) of these restraints are that they are so nebulous in definition (e.g. "good scientific practice") and open to ideological, or even political, manipulation apart from a rigorous practice of a scientific method, that they often serve to censor rather than promote scientific discovery. Apparent censorship through refusal to publish ideas unpopular with mainstream scientists (unpopular because of ideological reasons and/or because they seem to contradict long held scientific theories) has soured the popular perception of scientists as being neutral or seekers of truth and often denigrated popular perception of science as a whole.

Philosophy and sociology of science

Philosophy of science looks at the underpinning logic of the scientific method, at what separates science from non-science, and the ethic that is implicit in science. There are basic assumptions derived from philosophy that form the base of the scientific method - namely, that reality is objective and consistent, that humans have the capacity to perceive reality accurately, and that rational explanations exist for elements of the real world. These assumptions from methodological naturalism form the basis on which science is grounded. Logical Positivist, empiricist, falsificationist, and other theories have claimed to give a definitive account of the logic of science, but each has in turn been criticized.

Thomas Samuel Kuhn examined the history of science in his *The Structure of Scientific Revolutions*, and found that the actual method used by scientists differed dramatically from the then-espoused method. His observations of science practice are essentially sociological and do not speak to how science is or can be practiced in other times and other cultures.

Imre Lakatos and Thomas Kuhn have done extensive work on the "theory laden" character of observation. Kuhn (1961) said the scientist generally has a theory in mind before designing and undertaking experiments so as to make empirical observations, and that the "route from theory to measurement can almost never be traveled backward". This implies that the way in which theory is tested is dictated by the nature of the theory itself, which led Kuhn (1961, p. 166) to argue that "once it has been adopted by a profession ... no theory is recognized to be testable by any quantitative tests that it has not already passed".[79]

Paul Feyerabend similarly examined the history of science, and was led to deny that science is genuinely a methodological process. In his book *Against Method* he argues that scientific progress is *not* the result of applying any particular method. In essence, he says that "anything goes", by which he meant that for any specific methodology or norm of science, successful science has been done in violation of it.[80] Criticisms such as his led to the strong programme, a radical approach to the sociology of science.

In his 1958 book, *Personal Knowledge*, chemist and philosopher Michael Polanyi (1891–1976) criticized the common view that the scientific method is purely objective and generates objective knowledge. Polanyi cast this view as a misunderstanding of the scientific method and of the nature of scientific inquiry, generally. He argued that scientists do and must follow personal passions in appraising facts and in determining which scientific questions to investigate. He concluded that a structure of liberty is essential for the advancement of science - that the freedom to pursue science for its own sake is a prerequisite for the production of knowledge through peer review and the scientific method.

The postmodernist critiques of science have themselves been the subject of intense controversy. This ongoing debate, known as the science wars, is the result of conflicting values and assumptions between the postmodernist and realist camps. Whereas postmodernists assert that scientific knowledge is simply another discourse (note that this term has special meaning in this context) and not representative of any form of fundamental truth, realists in the scientific community maintain that scientific knowledge does reveal real and fundamental truths about reality. Many books have been written by scientists which take on this problem and challenge the assertions of the postmodernists while defending science as a legitimate method of deriving truth.[81]

History

The development of the scientific method is inseparable from the history of science itself. Ancient Egyptian documents describe empirical methods in astronomy,[82] mathematics,[83] and medicine.[84] The ancient Greek philosopher Thales in the 6th century BC refused to accept supernatural, religious or mythological explanations for natural phenomena, proclaiming that every event had a natural cause. The development of deductive reasoning by Plato was an important step towards the scientific method. Empiricism seems to have been formalized by Aristotle, who believed that universal truths could be reached via induction.

There are hints of experimental methods from the Classical world (e.g., those reported by Archimedes in a report recovered early in the 20th century CE from an overwritten manuscript), but the first clear instances of an experimental scientific method seem to have been developed in the Arabic world, by Muslim scientists See Alhazen, [85] , who introduced the use of experimentation and quantification to distinguish between competing scientific theories set within a generally empirical orientation, perhaps by Alhazen in his optical experiments reported in his *Book of Optics* (1021).[86] The modern scientific method crystallized no later than in the 17th and 18th centuries. In his work *Novum Organum* (1620) — a reference to Aristotle's *Organon* — Francis Bacon outlined a new system of logic to improve upon the old philosophical process of syllogism.[87] Then, in 1637, René Descartes established the framework for a scientific method's guiding principles in his treatise, *Discourse on Method*. The writings of Alhazen, Bacon and Descartes are considered critical in the historical development of the modern scientific method, as are those of John Stuart Mill.[88]

In the late 19th century, Charles Sanders Peirce proposed a schema that would turn out to have considerable influence in the development of current scientific method generally. Peirce accelerated the progress on several fronts. Firstly, speaking in broader context in "How to Make Our Ideas Clear" (1878) [89], Peirce outlined an objectively verifiable method to test the truth of putative knowledge on a way that goes beyond mere foundational alternatives, focusing upon both *deduction* and *induction*. He thus placed induction and deduction in a complementary rather than competitive context (the latter of which had been the primary trend at least since David Hume, who wrote in the mid-to-late 18th century). Secondly, and of more direct importance to modern method, Peirce put forth the basic schema for hypothesis/testing that continues to prevail today. Extracting the theory of inquiry from its raw materials in classical logic, he refined it in parallel with the early development of symbolic logic to address the then-current problems in scientific reasoning. Peirce examined and articulated the three fundamental modes of reasoning that, as discussed above in this article, play a role in inquiry today, the processes that are currently known as abductive, deductive, and inductive inference. Thirdly, he played a major role in the progress of symbolic logic itself — indeed this was his primary specialty.

Karl Popper denied the existence of evidence[90] and of scientific method.[91] Popper holds that there is only one universal method, the negative method of trial and error. It covers not only all products of the human mind, including science, mathematics, philosophy, art and so on, but also the evolution of life. Beginning in the 1930s he argued that empirical hypotheses must be falsifiable and that there is no such thing as inductive reasoning. Thus, all inferences ever made, including in science, are purely deductive according to Popper's view. Following Peirce and others, he argued that science is fallible and cannot be made certain or even probable. In contrast to empiricist-inductivist views, Popper welcomed metaphysics and philosophical discussion and even gave qualified support to myths and pseudosciences. Popper's view has become known as critical rationalism.

Relationship with mathematics

Science is the process of gathering, comparing, and evaluating proposed models against observables. A model can be a simulation, mathematical or chemical formula, or set of proposed steps. Science is like mathematics in that researchers in both disciplines can clearly distinguish what is *known* from what is *unknown* at each stage of discovery. Models, in both science and mathematics, need to be internally consistent and also ought to be *falsifiable* (capable of disproof). In mathematics, a statement need not yet be proven; at such a stage, that statement would be called a conjecture. But when a statement has attained mathematical proof, that statement gains a kind of immortality which is highly prized by mathematicians, and for which some mathematicians devote their lives.[92]

Mathematical work and scientific work can inspire each other.[93] For example, the technical concept of time arose in science, and timelessness was a hallmark of a mathematical topic. But today, the Poincaré conjecture has been proven using time as a mathematical concept in which objects can flow (see Ricci flow).

Nevertheless, the connection between mathematics and reality (and so science to the extent it describes reality) remains obscure. Eugene Wigner's paper, *The Unreasonable Effectiveness of Mathematics in the Natural Sciences*, is a very well-known account of the issue from a Nobel Prize physicist. In fact, some observers (including some well known mathematicians such as Gregory Chaitin, and others such as Lakoff and Núñez) have suggested that mathematics is the result of practitioner bias and human limitation (including cultural ones), somewhat like the post-modernist view of science.

George Pólya's work on problem solving,[94] the construction of mathematical proofs, and heuristic[95] [96] show that the mathematical method and the scientific method differ in detail, while nevertheless resembling each other in using iterative or recursive steps.

	Mathematical method	Scientific method
1	Understanding	Characterization from experience and observation
2	Analysis	Hypothesis: a proposed explanation
3	Synthesis	Deduction: prediction from the hypothesis
4	Review/Extend	Test and experiment

In Pólya's view, *understanding* involves restating unfamiliar definitions in your own words, resorting to geometrical figures, and questioning what we know and do not know already; *analysis*, which Pólya takes from Pappus,[97] involves free and heuristic construction of plausible arguments, working backward from the goal, and devising a plan for constructing the proof; *synthesis* is the strict Euclidean exposition of step-by-step details[98] of the proof; *review* involves reconsidering and re-examining the result and the path taken to it.

Gauss, when asked how he came about his theorems, once replied

- *durch planmässiges Tattonieren* (through systematic palpable experimentation). —Carl Friedrich Gauss[99]

See also

- Confirmability
- Logic
  - Abductive reasoning
  - Deductive reasoning
  - Inductive reasoning
  - Inference
  - Strong inference
  - Tautology
- Methodology
  - Baconian method
  - Empirical method
  - Historical method
  - Philosophical method
  - Phronetic method
  - Scholarly method
- Quantitative research
- Contingency
- Falsifiability
- Hypothesis
- Hypothesis testing
- Inquiry
- Information theory
- Mathematics
- OGHET
- Reproducibility
- Research
- Social research
- Statistics
- Testability
- Theory
- Verification and Validation

Problems and issues

- Induction
- Occam's razor
- Skeptical hypotheses
- Poverty of the stimulus
- Reference class problem
- Underdetermination
- Demarcation problem
- Holistic science
- Junk science
- Pseudoscience
- Scientific misconduct

History, philosophy, sociology

- Epistemology
- Epistemic truth
- History of science
- History of scientific method
- Instrumentalism
- Mertonian norms (Cudos)
- Philosophy of science
- Science studies
- Sociology of scientific knowledge
- Timeline of scientific method

Notes

[1] Goldhaber & Nieto 2010, p. 940

[2] "[4] Rules for the study of natural philosophy", Newton 1999, pp. 794–6, from Book **3**, *The System of the World*.

[3] scientific method (http://www.m-w.com/dictionary/scientific method), *Merriam-Webster Dictionary*.

[4] Morris Kline (1985) *Mathematics for the nonmathematician* (http://books.google.com/books?id=f-e0bro-0FUC&pg=PA284&dq&hl=en#v=onepage&q=&f=false). Courier Dover Publications. p. 284. ISBN 0-486-24823-2

[5] Peirce, C. S., *Collected Papers* v. 1, paragraph 74.

[6] Marshall Cavendish Corporation (2000). " *Exploring Life Science, Volume 9* (http://books.google.com/books?id=EDaOEw-Rv8MC&pg=PA658&dq&hl=en#v=onepage&q=&f=false)". Marshall Cavendish. p.658. ISBN 0-7614-7144-8

[7] Donal Parkerson, Jo Ann Parkerson (2008). " *The American Teacher: Foundations of Education* (http://books.google.com/books?id=CKtaRX1BbncC&pg=PA96&dq&hl=en#v=onepage&q=&f=false)". Taylor & Francis. p.96. ISBN 0-415-96387-7

[8] Kenneth John Atchity, Rosemary McKenna (1998). " *The classical Greek reader* (http://books.google.com/books?id=mOVpcmh9vTUC&pg=PR4&dq&hl=en#v=onepage&q=&f=false)". Oxford University Press US. ISBN 0-19-512303-4

[9] Alhazen (Ibn Al-Haytham) *Critique of Ptolemy*, translated by S. Pines, *Actes X Congrès internationale d'histoire des sciences*, Vol **I** Ithaca 1962, as quoted in Sambursky 1974, p. 139

[10] Alhazen, translated into English from German by M. Schwarz, from "Abhandlung über das Licht", J. Baarmann (ed. 1882) *Zeitschrift der Deutschen Morgenländischen Gesellschaft* Vol **36** as quoted in Sambursky 1974, p. 136

[11] as quoted in Sambursky 1974, p. 136

[12] "...the statement of a law—A depends on B—always transcends experience." —Born 1949, p. 6

[13] Taleb 2007 e.g., p. 58, devotes his chapter 5 to *the error of confirmation*.

[14] Galilei, Galileo (M.D.C.XXXVIII), *Discorsi e Dimonstrazioni Matematiche, intorno a due nuoue scienze*, Leida: Apresso gli Elsevirri, ISBN 0-486-60099-8, Dover reprint of the 1914 Macmillan translation by Henry Crew and Alfonso de Salvio of *Two New Sciences*, Galileo Galilei Linceo (1638). Additional publication information is from the collection of first editions of the Library of Congress by Leonard C. Bruno (1988), *The Landmarks of Science* ISBN 0-8160-2137-6

[15] "I believe that we do not know anything for certain, but everything probably." —Christiaan Huygens, Letter to Pierre Perrault, 'Sur la préface de M. Perrault de son traité del'Origine des fontaines' [1763], *Oeuvres Complétes de Christiaan Huygens* (1897), Vol. **7**, 298. Quoted in Jacques Roger, *The Life Sciences in Eighteenth-Century French Thought*, ed. Keith R. Benson and trans. Robert Ellrich (1997), 163. Quotation selected by Bynum & Porter 2005, p. 317 Huygens 317#4.

[16] As noted by Alice Calaprice (ed. 2005) *The New Quotable Einstein* Princeton University Press and Hebrew University of Jerusalem, ISBN 0-691-12074-9 p. 291. Calaprice denotes this not as an exact quotation, but as a paraphrase of a translation of A. Einstein's "Induction and Deduction". *Collected Papers of Albert Einstein* **7** Document 28. Volume 7 is *The Berlin Years: Writings, 1918-1921*. A. Einstein; M. Janssen, R. Schulmann, et al., eds.

[17] Hempel, Carl [The Internet Encyclopedia of Philosophy] (http://www.iep.utm.edu/h/hempel.htm)

[18] Poincaré 1905 p.142 notes that Francis Bacon introduced the term; on a related note, Ørsted introduced the term 'thought experiment'; of course, Galileo, a contemporary of Bacon, had previously made liberal use of these concepts in his writings centuries earlier than Poincaré or Ørsted.

[19] Fleck 1975, pp. xxvii-xxviii

[20] SCOPE - Salzberg, et al (http://www.sciencemag.org/feature/data/scope/keystone1/)

[21] October, 1951. as noted in McElheny 2004, p. 40:"That's what a helix should look like!" Crick exclaimed in delight (This is the Cochran-Crick-Vand&Stokes theory of the transform of a helix).

[22] June, 1952. as noted in McElheny 2004, p. 43: Watson had succeeded in getting X-ray pictures of TMV showing a helical pattern.

[23] Cochran W, Crick FHC and Vand V. (1952) "The Structure of Synthetic Polypeptides. I. The Transform of Atoms on a Helix", *Acta Cryst.*, **5**, 581-586.

[24] Friday, January 30, 1953. Tea time. as noted in McElheny 2004, p. 52: Franklin confronts Watson and his paper - "Of course it [Pauling's pre-print] is wrong. DNA is not a helix." Watson runs away from Franklin and runs into Wilkins; they retreat to Wilkins' office, where Wilkins shows Watson photo 51. Watson immediately recognizes the diffraction pattern of a helix.

[25] Saturday, February 28, 1953, as noted in McElheny 2004, pp. 57–59: Watson finds the base pairing which explains Chargaff's rules using his cardboard models.

[26] "People start off with a belief and a prejudice—we all do. And the job of science is to set that aside to get to the truth." —Simon Singh, as quoted in *Wired* (August 30, 2010) interview by Robert Capps (http://www.wired.com/magazine/2010/08/mf_qa_singh/)

[27] "Observation and experiment are subject to a very popular myth. ... The knower is seen as a ... Julius Caesar winning his battles according to ... formula. Even research workers will admit that the first observation may have been a little imprecise, whereas the second and third were 'adjusted to the facts' ... until tradition, education, and familiarity have produced *a readiness for stylized (that is directed and restricted) perception and action;* until an answer becomes largely pre-formed in the question, and a decision confined merely to 'yes' or 'no' or perhaps to a numerical determination; until methods and apparatus automatically carry out the greatest part of the mental work for us." Ludwik Fleck labels this *thought style*(*Denkstil*). Fleck 1975, p. 84.

[28] Needham & Wang 1954 p.166 shows how the 'flying gallop' image propagated from China to the West.

[29] Stanovich, 2007, pg 123

[30] "A myth is a belief given uncritical acceptance by members of a group ..." —Weiss, *Business Ethics* p. 15, as cited by Ronald R. Sims (2003) *Ethics and corporate social responsibility: why giants fall* p.21

[31] See the hypothethico-deductive method, for example, Godfrey-Smith 2003, p. 236.

[32] Jevons 1874, pp. 265–6.

[33] pp.65,73,92,398 —Andrew J. Galambos, *Sic Itur ad Astra* ISBN 0-88078-004-5(AJG learned scientific method from Felix Ehrenhaft

[34] Galilei 1638, pp. v-xii,1-300

[35] Brody 1993, pp. 10–24 calls this the "epistemic cycle": "The epistemic cycle starts from an initial model; iterations of the cycle then improve the model until an adequate fit is achieved."

[36] Iteration example: Chaldean astronomers such as Kidinnu compiled astronomical data. Hipparchus was to use this data to calculate the precession of the Earth's axis. Fifteen hundred years after Kidinnu, Al-Batani, born in what is now Turkey, would use the collected data and improve Hipparchus' value for the precession of the Earth's axis. Al-Batani's value, 54.5 arc-seconds per year, compares well to the current value of 49.8 arc-seconds per year (26,000 years for Earth's axis to round the circle of nutation).

[37] Recursion example: the Earth is itself a magnet, with its own North and South Poles William Gilbert (in Latin 1600) *De Magnete*, or *On Magnetism and Magnetic Bodies*. Translated from Latin to English, selection by Moulton & Schifferes 1960, pp. 113–117

[38] "The foundation of general physics ... is experience. These ... everyday experiences we do not discover without deliberately directing our attention to them. Collecting information about these is *observation*." —Hans Christian Ørsted("First Introduction to General Physics" ¶13, part of a series of public lectures at the University of Copenhagen. Copenhagen 1811, in Danish, printed by Johan Frederik Schulz. In Kirstine Meyer's 1920 edition of Ørsted's works, vol.**III** pp. 151-190.) "First Introduction to Physics: the Spirit, Meaning, and Goal of Natural Science". Reprinted in German in 1822, Schweigger's *Journal für Chemie und Physik* **36**, pp.458-488, as translated in Ørsted 1997, p. 292

[39] "When it is not clear under which law of nature an effect or class of effect belongs, we try to fill this gap by means of a guess. Such guesses have been given the name *conjectures* or *hypotheses*." —Hans Christian Ørsted(1811) "First Introduction to General Physics" as translated in Ørsted 1997, p. 297.

[40] "In general we look for a new law by the following process. First we guess it. ...", —Feynman 1965, p. 156

[41] "... the statement of a law - A depends on B - always transcends experience."—Born 1949, p. 6

[42] "The student of nature ... regards as his property the experiences which the mathematician can only borrow. This is why he deduces theorems directly from the nature of an effect while the mathematician only arrives at them circuitously." —Hans Christian Ørsted(1811) "First Introduction to General Physics" ¶17. as translated in Ørsted 1997, p. 297.

[43] Salviati speaks: "I greatly doubt that Aristotle ever tested by experiment whether it be true that two stones, one weighing ten times as much as the other, if allowed to fall, at the same instant, from a height of, say, 100 cubits, would so differ in speed that when the heavier had reached the ground, the other would not have fallen more than 10 cubits." Two New Sciences (1638) (http://galileo.phys.virginia.edu/classes/109N/tns61.htm) —Galilei 1638, pp. 61–62. A more extended quotation is referenced by Moulton & Schifferes 1960, pp. 80–81.

[44] In the inquiry-based education paradigm, the stage of "characterization, observation, definition, …" is more briefly summed up under the rubric of a Question

[45] "To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science." —Einstein & Infeld 1938, p. 92.

[46] Crawford S, Stucki L (1990), "Peer review and the changing research record", "J Am Soc Info Science", vol. 41, pp 223-228

[47] *See, e.g.*, Gauch 2003, esp. chapters 5-8

[48] Cartwright, Nancy (1983), *How the Laws of Physics Lie*. Oxford: Oxford University Press. ISBN 0-19-824704-4

[49] Andreas Vesalius, *Epistola, Rationem, Modumque Propinandi Radicis Chynae Decocti* (1546), 141. Quoted and translated in C.D. O'Malley, *Andreas Vesalius of Brussels*, (1964), 116. As quoted by Bynum & Porter 2005, p. 597: Andreas Vesalius,597#1.

[50] Crick, Francis (1994), *The Astonishing Hypothesis* ISBN 0-684-19431-7 p.20

[51] Glen 1994, pp. 37–38.

[52] "The structure that we propose is a three-chain structure, each chain being a helix" — Linus Pauling, as quoted on p. 157 by Horace Freeland Judson (1979), *The Eighth Day of Creation* ISBN 0-671-22540-5

[53] McElheny 2004, pp. 49–50: January 28, 1953 - Watson read Pauling's pre-print, and realized that in Pauling's model, DNA's phosphate groups had to be un-ionized. But DNA is an acid, which contradicts Pauling's model.

[54] June, 1952. as noted in McElheny 2004, p. 43: Watson had succeeded in getting X-ray pictures of TMV showing a diffraction pattern consistent with the transform of a helix.

[55] Watson did enough work on Tobacco mosaic virus to produce the diffraction pattern for a helix, per Crick's work on the transform of a helix. pp. 137-138, Horace Freeland Judson (1979) *The Eighth Day of Creation* ISBN 0-671-22540-5

[56] In March 1917, the Royal Astronomical Society announced that on May 29, 1919, the occasion of a total eclipse of the sun would afford favorable conditions for testing Einstein's General theory of relativity. One expedition, to Sobral, Ceará, Brazil, and Eddington's expedition to the island of Principe yielded a set of photographs, which, when compared to photographs taken at Sobral and at Greenwich Observatory showed that the deviation of light was measured to be 1.69 arc-seconds, as compared to Einstein's desk prediction of 1.75 arc-seconds. — Antonina Vallentin (1954), *Einstein*, as quoted by Samuel Rapport and Helen Wright (1965), *Physics*, New York: Washington Square Press, pp 294-295.

[57] Mill, John Stuart, "A System of Logic", University Press of the Pacific, Honolulu, 2002, ISBN 1-4102-0252-6.

[58] http://www.pbs.org/wgbh/nova/photo51/

[59] "The instant I saw the picture my mouth fell open and my pulse began to race." —Watson 1968, p. 167 Page 168 shows the X-shaped pattern of the B-form of DNA, clearly indicating crucial details of its helical structure to Watson and Crick.

[60] "Suddenly I became aware that an adenine-thymine pair held together by two hydrogen bonds was identical in shape to a guanine-cytosine pair held together by at least two hydrogen bonds. ..." —Watson 1968, pp. 194–197.

[61] See, e.g., *Physics Today*, **59**(1), p42. Richmann electrocuted in St. Petersburg (1753) (http://ptonline.aip.org/journals/doc/PHTOAD-ft/vol_59/iss_1/42_1.shtml?bypassSSO=1)

[62] Aristotle, "Prior Analytics", Hugh Tredennick (trans.), pp. 181-531 in *Aristotle, Volume 1*, Loeb Classical Library, William Heinemann, London, UK, 1938.

[63] Peirce (1877), "The Fixation of Belief", *Popular Science Monthly*, v. 12, pp. 1–15. Reprinted often, including (*Collected Papers of Charles Sanders Peirce* v. 5, paragraphs 358–87), (*The Essential Peirce*, v. 1, pp. 109–23). *Peirce.org* Eprint (http://www.peirce.org/writings/p107.html). *Wikisource* Eprint.

[64] Peirce held that actual, genuine doubt originates externally, usually in surprise, but hardly denied that it can and should be sought and cultivated, "provided only that it be the weighty and noble metal itself, and no counterfeit nor paper substitute." In "Issues of Pragmaticism", *The Monist*, v. XV, n. 4, pp. 481-99, see p. 484 (http://www.archive.org/stream/monistquart15hegeuoft#page/484/mode/1up), and p. 491 (http://www.archive.org/stream/monistquart15hegeuoft#page/491/mode/1up). (Reprinted in *Collected Papers* v. 5, paragraphs 438-63, see 443 and 451).

[65] Peirce (1898), "Philosophy and the Conduct of Life", Lecture 1 of the Cambridge (MA) Conferences Lectures, published in *Collected Papers* v. 1, paragraphs 616-48 in part and in *Reasoning and the Logic of Things*, Ketner (ed., intro.) and Putnam (intro., comm.), pp. 105-22, reprinted in *Essential Peirce* v. 2, pp. 27-41.

[66] Peirce (1899), "F.R.L." [First Rule of Logic], *Collected Papers* v. 1, paragraphs 135-40, Eprint (http://www.princeton.edu/~batke/peirce/frl_99.htm)

[67] *Collected Papers* v. 5, in paragraph 582, from 1898:

> ... [rational] inquiry of every type, fully carried out, has the vital power of self-correction and of growth. This is a property so deeply saturating its inmost nature that it may truly be said that there is but one thing needful for learning the truth, and that is a hearty and active desire to learn what is true.

[68] Peirce (1877), "How to Make Our Ideas Clear", *Popular Science Monthly*, v. 12, pp. 286–302. Reprinted often, including *Collected Papers* v. 5, paragraphs 388–410, *Essential Peirce* v. 1, pp. 124–41. *Arisbe* Eprint (http://www.cspeirce.com/menu/library/bycsp/ideas/id-frame.htm). *Wikisource* Eprint.

[69] Peirce (1868), "Some Consequences of Four Incapacities", *Journal of Speculative Philosophy* v. 2, n. 3, pp. 140–57. Reprinted *Collected Papers* v. 5, paragraphs 264–317, *The Essential Peirce* v. 1, pp. 28–55, and elsewhere. *Arisbe* Eprint (http://www.cspeirce.com/menu/library/bycsp/conseq/cn-frame.htm)

[70] Peirce (1878), "The Doctrine of Chances", *Popular Science Monthly* v. 12, pp. 604-15, see pp. 610 (http://www.archive.org/stream/popscimonthly12yoummiss#page/618/mode/1up)-11 via *Internet Archive*. Reprinted *Collected Papers* v. 2, paragraphs 645-68, *Essential Peirce* v. 1, pp. 142-54. "...death makes the number of our risks, the number of our inferences, finite, and so makes their mean result uncertain. The very idea of probability and of reasoning rests on the assumption that this number is indefinitely great. ....logicality inexorably requires that our interests shall not be limited. .... Logic is rooted in the social principle."

[71] Peirce (1908), "A Neglected Argument for the Reality of God", *Hibbert Journal* v. 7, pp. 90-112. *Wikisource* Eprint with added notes. Reprinted often, with previously unpublished part, including (*Collected Papers* v. 6, paragraphs 452-85), (*The Essential Peirce* v. 2, pp. 434-50).

[72] Peirce (c. 1906), "PAP (Prolegomena for an Apology to Pragmatism)" (Manuscript 293, not the like-named article), *The New Elements of Mathematics* (NEM) 4:319-320, see first quote under " Abduction (http://www.helsinki.fi/science/commens/terms/abduction.html)" at *Commens Dictionary of Peirce's Terms*.

[73] Peirce, Carnegie application (L75, 1902), *New Elements of Mathematics* v. 4, pp. 37-38:

For it is not sufficient that a hypothesis should be a justifiable one. Any hypothesis which explains the facts is justified critically. But among justifiable hypotheses we have to select that one which is suitable for being tested by experiment.

[74] Peirce (1902), Carnegie application, see MS L75.329-330, from Draft D (http://www.cspeirce.com/menu/library/bycsp/l75/ver1/l75v1-08.htm#m27) of Memoir 27:

Consequently, to discover is simply to expedite an event that would occur sooner or later, if we had not troubled ourselves to make the discovery. Consequently, the art of discovery is purely a question of economics. The economics of research is, so far as logic is concerned, the leading doctrine with reference to the art of discovery. Consequently, the conduct of abduction, which is chiefly a question of heuretic and is the first question of heuretic, is to be governed by economical considerations.

[75] Peirce (1903), "Pragmatism — The Logic of Abduction", *Collected Papers* v. 5, paragraphs 195-205, especially 196. Eprint (http://www.textlog.de/7663.html).

[76] Peirce, "On the Logic of Drawing Ancient History from Documents", *Essential Peirce* v. 2, see pp. 107-9. On Twenty Questions, p. 109:

Thus, twenty skillful hypotheses will ascertain what 200,000 stupid ones might fail to do.

[77] Peirce (1878), "The Probability of Induction", *Popular Science Monthly*, v. 12, pp. 705-18, *Google Books* Eprint (http://books.google.com/books?id=ZKMVAAAAYAAJ&pg=PA705), *Internet Archive* Eprint (http://www.archive.org/stream/popscimonthly12yoummiss#page/715/mode/1up). Reprinted often, including (*Collected Papers* v. 2, paragraphs 669-93), (*The Essential Peirce* v. 1, pp. 155-69).

[78] http://www.nature.com/nature/submit/get_published/index.html

[79] Kuhn, Thomas S., "The Function of Measurement in Modern Physical Science", *ISIS* 52(2), 161–193, 1961.

[80] Feyerabend, Paul K., *Against Method, Outline of an Anarchistic Theory of Knowledge*, 1st published, 1975. Reprinted, Verso, London, UK, 1978.

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- *A House Built on Sand: Exposing Postmodernist Myths About Science*, Oxford University Press, 2000
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[82] The ancient Egyptians observed that heliacal rising of a certain star, *Sothis* (Greek for *Sopdet* (Egyptian), known to the West as *Sirius*), marked the annual flooding of the Nile river. See Neugebauer, Otto (1969) [1957], *The Exact Sciences in Antiquity* (http://books.google.com/?id=JVhTtVA2zr8C) (2 ed.), Dover Publications, ISBN 978-048622332-2, , p.82, and also the 1911 *Britannica*, "Egypt".

[83] The Rhind papyrus lists practical examples in arithmetic and geometry —1911 *Britannica*, "Egypt".

[84] The Ebers papyrus lists some of the 'mysteries of the physician', as cited in the 1911 *Britannica*, "Egypt"

[85] Critique of Ptolemy as referenced in {Sambursky|1974|p=139}

[86] Rosanna Gorini (2003), "Al-Haytham the Man of Experience, First Steps in the Science of Vision", *International Society for the History of Islamic Medicine*, Institute of Neurosciences, Laboratory of Psychobiology and Psychopharmacology, Rome, Italy:

"According to the majority of the historians al-Haytham was the pioneer of the modern scientific method. With his book he changed the meaning of the term optics and established experiments as the norm of proof in the field. His investigations are based not on abstract theories, but on experimental evidences and his experiments were systematic and repeatable."

[87] Bacon, Francis *Novum Organum (The New Organon)*, 1620. Bacon's work described many of the accepted principles, underscoring the importance of theory, empirical results, data gathering, experiment, and independent corroboration.

[88] "John Stuart Mill (Stanford Encyclopedia of Philosophy)" (http://plato.stanford.edu/entries/mill/#SciMet). plato.stanford.edu. . Retrieved 2009-07-31.

[89] http://www.cspeirce.com/menu/library/bycsp/ideas/id-frame.htm

[90] *Logik der Forschung*, new appendix **XIX* (not yet available in the English edition *Logic of scientific discovery*)

[91] Karl Popper: On the non-existence of scientific method. *Realism and the Aim of Science* (1983)

[92] "When we are working intensively, we feel keenly the progress of our work; we are elated when our progress is rapid, we are depressed when it is slow." — the mathematician Pólya 1957, p. 131 in the section on 'Modern heuristic'.

[93] "Philosophy [i.e., physics] is written in this grand book--I mean the universe--which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures, without which it is humanly impossible to understand a single word of it; without these, one is wandering around in a dark labyrinth." —Galileo Galilei, *Il Saggiatore* (*The Assayer*, 1623), as translated by Stillman Drake (1957), *Discoveries and Opinions of Galileo* pp. 237-8, as quoted by di Francia 1981, p. 10.

[94] Pólya 1957 2nd ed.

[95] George Pólya (1954), *Mathematics and Plausible Reasoning Volume I: Induction and Analogy in Mathematics*,

[96] George Pólya (1954), *Mathematics and Plausible Reasoning Volume II: Patterns of Plausible Reasoning*.
[97] Pólya 1957, p. 142
[98] Pólya 1957, p. 144
[99] Mackay 1991 p.100

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External links

- An Introduction to Science: Scientific Thinking and a scientific method (http://www.freeinquiry.com/intro-to-sci.html) by Steven D. Schafersman.
- Introduction to a scientific method (http://teacher.nsrl.rochester.edu/phy_labs/AppendixE/AppendixE.html)
- Theory-ladenness (http://www.galilean-library.org/theory.html) by Paul Newall at The Galilean Library
- Lecture on Scientific Method by Greg Anderson (http://web.archive.org/web/20060428080832/http://pasadena.wr.usgs.gov/office/ganderson/es10/lectures/lecture01/lecture01.html)
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- SCIENTIFIC METHODS an online book by Richard D. Jarrard (http://emotionalcompetency.com/sci/booktoc.html)
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Statistical hypothesis testing

A **statistical hypothesis test** is a method of making decisions using experimental data. In statistics, a result is called **statistically significant** if it is unlikely to have occurred by chance. The phrase "*test of significance*" was coined by Ronald Fisher: "Critical tests of this kind may be called tests of significance, and when such tests are available we may discover whether a second sample is or is not significantly different from the first."[1]

Hypothesis testing is sometimes called **confirmatory data analysis**, in contrast to exploratory data analysis. In frequency probability, these decisions are almost always made using null-hypothesis tests (i.e., tests that answer the question *Assuming that the null hypothesis is true, what is the probability of observing a value for the test statistic that is at least as extreme as the value that was actually observed?*)[2] One use of hypothesis testing is deciding whether experimental results contain enough information to cast doubt on conventional wisdom.

Statistical hypothesis testing is a key technique of frequentist statistical inference, and is widely used, but also much criticized. While controversial,[3] the Bayesian approach to hypothesis testing is to base rejection of the hypothesis on the posterior probability.[4] Other approaches to reaching a decision based on data are available via decision theory and optimal decisions.

The *critical region* of a hypothesis test is the set of all outcomes which, if they occur, will lead us to decide that there is a difference. That is, cause the null hypothesis to be rejected in favor of the alternative hypothesis. The critical region is usually denoted by C.

Examples

The following examples should solidify these ideas.

Example 1 - Court Room Trial

A statistical test procedure is comparable to a trial; a defendant is considered not guilty as long as his guilt is not proven. The prosecutor tries to prove the guilt of the defendant. Only when there is enough charging evidence the defendant is condemned.

In the start of the procedure, there are two hypotheses H_0: "the defendant is not guilty", and H_1: "the defendant is guilty". The first one is called *null hypothesis*, and is for the time being accepted. The second one is called *alternative (hypothesis)*. It is the hypothesis one tries to prove.

The hypothesis of innocence is only rejected when an error is very unlikely, because one doesn't want to condemn an innocent defendant. Such an error is called *error of the first kind* (i.e. the condemnation of an innocent person), and the occurrence of this error is controlled to be rare. As a consequence of this asymmetric behaviour, the *error of the second kind* (setting free a guilty person), is often rather large.

	Null Hypothesis (H_0) is true **He truly is not guilty**	**Alternative Hypothesis (H_1) is true** **He truly is guilty**
Accept Null Hypothesis	Right decision	Wrong decision Type II Error
Reject Null Hypothesis	Wrong decision Type I Error	Right decision

Example 2 - Clairvoyant Card Game

A person (the subject) is tested for clairvoyance. He is shown the reverse of a randomly chosen play card 25 times and asked which suit it belongs to. The number of hits, or correct answers, is called *X*.

As we try to find evidence of his clairvoyance, for the time being the null hypothesis is that the person is not clairvoyant. The alternative is, of course: the person is (more or less) clairvoyant.

If the null hypothesis is valid, the only thing the test person can do is guess. For every card, the probability (relative frequency) of guessing correctly is 1/4. If the alternative is valid, the test subject will predict the suit correctly with probability greater than 1/4. We will call the probability of guessing correctly *p*. The hypotheses, then, are:

- null hypothesis : $H_0 : p = \frac{1}{4}$ (just guessing)

and

- alternative hypothesis : $H_1 : p > \frac{1}{4}$ (true clairvoyant).

When the test subject correctly predicts all 25 cards, we will consider him clairvoyant, and reject the null hypothesis. Thus also with 24 or 23 hits. With only 5 or 6 hits, on the other hand, there is no cause to consider him so. But what about 12 hits, or 17 hits? What is the critical number, *c*, of hits, at which point we consider the subject to be clairvoyant? How do we determine the critical value *c*? It is obvious that with the choice *c*=25 (i.e. we only accept clairvoyance when all cards are predicted correctly) we're more critical than with *c*=10. In the first case almost no test subjects will be recognized to be clairvoyant, in the second case, some number more will pass the test. In practice, one decides how critical one will be. That is, one decides how often one accepts an error of the first kind - a false positive, or Type I error. With *c* = 25 the probability of such an error is:

and hence, very small. The probability of a false positive is the probability of randomly guessing correctly all 25 times.

Being less critical, with *c*=10, gives:

$$P(\text{reject } H_0 | H_0 \text{ is valid}) = P(X \geq 10 | p = \tfrac{1}{4}) \approx 0.07.$$

Thus, *c*=10 yields a much greater probability of false positive.

Before the test is actually performed, the desired probability of a Type I error is determined. Typically, values in the range of 1% to 5% are selected. Depending on this desired Type 1 error rate, the critical value *c* is calculated. For example, if we select an error rate of 1%, *c* is calculated thus:

$$P(\text{reject } H_0 | H_0 \text{ is valid}) = P(X \geq c | p = \tfrac{1}{4}) \leq 0.01.$$

From all the numbers c, with this property, we choose the smallest, in order to minimize the probability of a Type II error, a false negative. For the above example, we select: $c = 12$.

But what if the subject did not guess any cards at all? Having zero correct answers is clearly an oddity too. The probability of guessing incorrectly once is equal to p'=(1-p)=3/4. Using the same approach we can calculate that probability of randomly calling all 25 cards wrong is:

This is highly unlikely (less than 1 in a 1000 chance). While the subject can't guess the cards correctly, dismissing H_0 in favour of H_1 would be an error. In fact, the result would suggest a trait on the subject's part of avoiding calling the correct card. A test of this could be formulated: for a selected 1% error rate the subject would have to answer correctly at least twice, for us to believe that card calling is based purely on guessing.

Example 3 - Radioactive Suitcase

As an example, consider determining whether a suitcase contains some radioactive material. Placed under a Geiger counter, it produces 10 counts per minute. The null hypothesis is that no radioactive material is in the suitcase and that all measured counts are due to ambient radioactivity typical of the surrounding air and harmless objects. We can then calculate how likely it is that we would observe 10 counts per minute if the null hypothesis were true. If the null hypothesis predicts (say) on average 9 counts per minute and a standard deviation of 1 count per minute, then we say that the suitcase is compatible with the null hypothesis (this does not guarantee that there is no radioactive material, just that we don't have enough evidence to suggest there is). On the other hand, if the null hypothesis predicts 3 counts per minute and a standard deviation of 1 count per minute, then the suitcase is not compatible with the null hypothesis, and there are likely other factors responsible to produce the measurements.

The test described here is more fully the null-hypothesis statistical significance test. The null hypothesis represents what we would believe by default, before seeing any evidence. Statistical significance is a possible finding of the test, declared when the observed sample is unlikely to have occurred by chance if the null hypothesis were true. The name of the test describes its formulation and its possible outcome. One characteristic of the test is its crisp decision: to reject or not reject the null hypothesis. A calculated value is compared to a threshold, which is determined from the tolerable risk of error.

The designer of a statistical test wants to maximize the good probabilities and minimize the bad probabilities. Implicit in the design is the assumption that neither the briefcase nor the Geiger counter move. For laboratory tests and thought experiments the assumption of stationarity is often valid. For most measured data in the natural and social sciences one must consider the location of the measuring device(s) and the location of the measured object(s) when applying hypothesis testing in spatial statistics.

Example 4 - Lady Tasting Tea

The following example is summarized from Fisher, and is known as the *Lady tasting tea* example.[5] Fisher thoroughly explained his method in a proposed experiment to test a Lady's claimed ability to determine the means of tea preparation by taste. The article is less than 10 pages in length and is notable for its simplicity and completeness regarding terminology, calculations and design of the experiment. The example is loosely based on an event in Fisher's life. The Lady proved him wrong.[6]

1. The null hypothesis was that the Lady had no such ability.
2. The test statistic was a simple count of the number of successes in 8 trials.
3. The distribution associated with the null hypothesis was the binomial distribution familiar from coin flipping experiments.
4. The critical region was the single case of 8 successes in 8 trials based on a conventional probability criterion (< 5%).
5. Fisher asserted that no alternative hypothesis was (ever) required.

If and only if the 8 trials produced 8 successes was Fisher willing to reject the null hypothesis – effectively acknowledging the Lady's ability with > 98% confidence (but without quantifying her ability). Fisher later discussed the benefits of more trials and repeated tests.

The Testing Process

Hypothesis testing is defined by the following general procedure:

1. The first step in any hypothesis testing is to state the relevant **null and alternative hypotheses** to be tested. This is important as mis-stating the hypotheses will muddy the rest of the process.
2. The second step is to consider the statistical assumptions being made about the sample in doing the test; for example, assumptions about the statistical independence or about the form of the distributions of the observations. This is equally important as invalid assumptions will mean that the results of the test are invalid.
3. Decide which test is appropriate, and stating the relevant **test statistic** T.
4. Derive the distribution of the test statistic under the null hypothesis from the assumptions. In standard cases this will be a well-known result. For example the test statistics may follow a Student's t distribution or a normal distribution.
5. The distribution of the test statistic partitions the possible values of T into those for which the null-hypothesis is rejected, the so called critical region, and those for which it is not.
6. Compute from the observations the observed value t_{obs} of the test statistic T.
7. Decide to either **fail to reject** the null hypothesis or **reject** it in favor of the alternative. The decision rule is to reject the null hypothesis H_0 if the observed value t_{obs} is in the critical region, and to accept or "fail to reject" the hypothesis otherwise.

It is important to note the philosophical difference between accepting the null hypothesis and simply failing to reject it. The "fail to reject" terminology highlights the fact that the null hypothesis is assumed to be true from the start of the test; if there is a lack of evidence against it, it simply continues to be assumed true. The phrase "accept the null hypothesis" may suggest it has been proved simply because it has not been disproved, a logical fallacy known as the argument from ignorance. Unless a test with particularly high power is used, the idea of "accepting" the null hypothesis may be dangerous. Nonetheless the terminology is prevalent throughout statistics, where its meaning is well understood.

Definition of terms

The following definitions are mainly based on the exposition in the book by Lehmann and Romano:[7]

Simple hypothesis

Any hypothesis which specifies the population distribution completely.

Composite hypothesis

Any hypothesis which does *not* specify the population distribution completely.

Statistical test

A decision function that takes its values in the set of hypotheses.

Region of acceptance

The set of values for which we fail to reject the null hypothesis.

Region of rejection / Critical region

The set of values of the test statistic for which the null hypothesis is rejected.

Power of a test ($1 - \beta$)

The test's probability of correctly rejecting the null hypothesis. The complement of the false negative rate, β.

Size / Significance level of a test (α)

For simple hypotheses, this is the test's probability of *incorrectly* rejecting the null hypothesis. The false positive rate. For composite hypotheses this is the upper bound of the probability of rejecting the null hypothesis over all cases covered by the null hypothesis.

Most powerful test

For a given *size* or *significance level*, the test with the greatest power.

Uniformly most powerful test (UMP)

A test with the greatest *power* for all values of the parameter being tested.

Consistent test

When considering the properties of a test as the sample size grows, a test is said to be consistent if, for a fixed size of test, the power against any fixed alternative approaches 1 in the limit.[8]

Unbiased test

For a specific alternative hypothesis, a test is said to be **unbiased** when the probability of rejecting the null hypothesis is not less than the significance level when the alternative is true *and* is less than or equal to the significance level when the null hypothesis is true.

Conservative test

A test is conservative if, when constructed for a given nominal significance level, the true probability of *incorrectly* rejecting the null hypothesis is never greater than the nominal level.

Uniformly most powerful unbiased (UMPU)

A test which is UMP in the set of all unbiased tests.

p-value

The probability, assuming the null hypothesis is true, of observing a result at least as extreme as the test statistic.

Interpretation

The direct interpretation is that if the p-value is less than the required significance level, then we say the null hypothesis is rejected at the given level of significance. Criticism on this interpretation can be found in the corresponding section.

Common test statistics

In the table below, the symbols used are defined at the bottom of the table. Many other tests can be found in other articles.

Name	Formula	Assumptions or notes
One-sample z-test	$z=\frac{\overline{x}-\mu_0}{(\sigma/\sqrt{n})}$	(Normal population **or** $n > 30$) **and** σ known. (z is the distance from the mean in relation to the standard deviation of the mean). For non-normal distributions it is possible to calculate a minimum proportion of a population that falls within k standard deviations for any k (see: *Chebyshev's inequality*).
Two-sample z-test	$z=\frac{(\overline{x}_1-\overline{x}_2)-d_0}{\sqrt{\frac{\sigma_1^2}{n_1}+\frac{\sigma_2^2}{n_2}}}$	Normal population **and** independent observations **and** σ_1 and σ_2 are known
Two-sample pooled t-test, equal variances*	$t=\frac{(\overline{x}_1-\overline{x}_2)-d_0}{s_p\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}},$ $s_p^2=\frac{(n_1-1)s_1^2+(n_2-1)s_2^2}{n_1+n_2-2},$ $df=n_1+n_2-2$[9]	(Normal populations **or** $n_1 + n_2 > 40$) **and** independent observations **and** $\sigma_1 = \sigma_2$ **and** σ_1 and σ_2 unknown

Two-sample unpooled t-test, unequal variances*	$t=\frac{(\overline{x}_1-\overline{x}_2)-d_0}{\sqrt{\frac{s_1^2}{n_1}+\frac{s_2^2}{n_2}}}$, $df=\frac{\left(\frac{s_1^2}{n_1}+\frac{s_2^2}{n_2}\right)^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n_1-1}+\frac{\left(\frac{s_2^2}{n_2}\right)^2}{n_2-1}}$ [9]	(Normal populations **or** $n_1 + n_2 > 40$) **and** independent observations **and** $\sigma_1 \neq \sigma_2$ **and** σ_1 and σ_2 unknown
One-proportion z-test	$z=\frac{\hat{p}-p_0}{\sqrt{\frac{p_0(1-p_0)}{n}}}$	$n \cdot p_0 > 10$ **and** $n(1 - p_0) > 10$ **and** it is a SRS (Simple Random Sample), see notes.
Two-proportion z-test, pooled for $d_0 = 0$	$z=\frac{(\hat{p}_1-\hat{p}_2)-d_0}{\sqrt{\hat{p}(1-\hat{p})(\frac{1}{n_1}+\frac{1}{n_2})}}$ $\hat{p}=\frac{x_1+x_2}{n_1+n_2}$	$n_1 p_1 > 5$ **and** $n_1(1 - p_1) > 5$ **and** $n_2 p_2 > 5$ **and** $n_2(1 - p_2) > 5$ **and** independent observations, see notes.
Two-proportion z-test, unpooled for $\|d_0\| > 0$	$z=\frac{(\hat{p}_1-\hat{p}_2)-d_0}{\sqrt{\frac{\hat{p}_1(1-\hat{p}_1)}{n_1}+\frac{\hat{p}_2(1-\hat{p}_2)}{n_2}}}$	$n_1 p_1 > 5$ **and** $n_1(1 - p_1) > 5$ **and** $n_2 p_2 > 5$ **and** $n_2(1 - p_2) > 5$ **and** independent observations, see notes.
One-sample chi-square test	$\chi^2=\frac{(n-1)s^2}{\sigma_0^2}$	One of the following • All expected counts are at least 5 • All expected counts are > 1 and no more that 20% of expected counts are less than 5
*Two-sample F test for equality of variances	$F=\frac{s_1^2}{s_2^2}$	Arrange so $s_1^2 \geq s_2^2$ and reject H_0 for $F > F(\alpha/2, n_1-1, n_2-1)$ [10]

In general, the subscript 0 indicates a value taken from the null hypothesis, H_0, which should be used as much as possible in constructing its test statistic. ... *Definitions of other symbols:*

- α, the probability of Type I error (rejecting a null hypothesis when it is in fact true)
- n = sample size
- n_1 = sample 1 size
- n_2 = sample 2 size
- $\overline{x}$ = sample mean
- μ_0 = hypothesized population mean
- μ_1 = population 1 mean
- μ_2 = population 2 mean
- σ = population standard deviation
- σ^2 = population variance
- s = sample standard deviation
- s^2 = sample variance
- s_1 = sample 1 standard deviation
- s_2 = sample 2 standard deviation
- t = t statistic
- df = degrees of freedom
- $\overline{d}$ = sample mean of differences
- d_0 = hypothesized population mean difference
- s_d = standard deviation of differences
- $\hat{p} = x/n$ = sample proportion, unless specified otherwise
- p_0 = hypothesized population proportion
- p_1 = proportion 1
- p_2 = proportion 2
- d_p = hypothesized difference in proportion
- $\min\{n_1, n_2\}$ = minimum of n_1 and n_2
- $x_1 = n_1 p_1$
- $x_2 = n_2 p_2$
- χ^2 = Chi-squared statistic
- F = F statistic

Origins

Hypothesis testing is largely the product of Ronald Fisher, Jerzy Neyman, Karl Pearson and (son) Egon Pearson. Fisher was an agricultural statistician who emphasized rigorous experimental design and methods to extract a result from few samples assuming Gaussian distributions. Neyman (who teamed with the younger Pearson) emphasized mathematical rigor and methods to obtain more results from many samples and a wider range of distributions. Modern hypothesis testing is an (extended) hybrid of the Fisher vs Neyman/Pearson formulation, methods and terminology developed in the early 20th century.

Importance

Statistical hypothesis testing plays an important role in the whole of statistics and in statistical inference. For example, Lehmann (1992) in a review of the fundamental paper by Neyman and Pearson (1933) says: "Nevertheless, despite their shortcomings, the new paradigm formulated in the 1933 paper, and the many developments carried out within its framework continue to play a central role in both the theory and practice of statistics and can be expected to do so in the foreseeable future".

Potential misuse

One of the more common problems in significance testing is the tendency for multiple comparisons to yield spurious significant differences even where the null hypothesis is true. For instance, in a study of twenty comparisons, using an α-level of 5%, one comparison will likely yield a significant result despite the null hypothesis being true. In these cases p-values are adjusted in order to control either the familywise error rate or the false discovery rate.

Yet another common pitfall often happens when a researcher writes the qualified statement "we found no statistically significant difference," which is then misquoted by others as "they found that there was no difference." Actually, statistics cannot be used to prove that there is exactly zero difference between two populations. Failing to find evidence that there is a difference does not constitute evidence that there is no difference. This principle is sometimes described by the maxim "Absence of evidence is not evidence of absence."[11]

According to J. Scott Armstrong, attempts to educate researchers on how to avoid pitfalls of using statistical significance have had little success. In the papers "Significance Tests Harm Progress in Forecasting,"[12] and "Statistical Significance Tests are Unnecessary Even When Properly Done,"[13] Armstrong makes the case that even when done properly, statistical significance tests are of no value. A number of attempts failed to find empirical evidence supporting the use of significance tests. Tests of statistical significance are harmful to the development of scientific knowledge because they distract researchers from the use of proper methods. Armstrong suggests authors should avoid tests of statistical significance; instead, they should report on effect sizes, confidence intervals, replications/extensions, and meta-analyses.

Criticism

Significance and practical importance

A common misconception is that a statistically significant result is always of practical significance, or demonstrates a large effect in the population. Unfortunately, this problem is commonly encountered in scientific writing.[14] Given a sufficiently large sample, extremely small and non-notable differences can be found to be statistically significant, and statistical significance says nothing about the practical significance of a difference.

Use of the statistical significance test has been called seriously flawed and unscientific by authors Deirdre McCloskey and Stephen Ziliak. They point out that "insignificance" does not mean unimportant, and propose that the scientific community should abandon usage of the test altogether, as it can cause false hypotheses to be accepted and true hypotheses to be rejected.[14] [15]

Some statisticians have commented that pure "significance testing" has what is actually a rather strange goal of detecting the existence of a "real" difference between two populations. In practice a difference can almost always be found given a large enough sample. The typically more relevant goal of science is a determination of causal effect size. The amount and nature of the difference, in other words, is what should be studied.[16] Many researchers also feel that hypothesis testing is something of a misnomer. In practice a single statistical test in a single study never "proves" anything.[17]

An additional problem is that frequentist analyses of p-values are considered by some to overstate "statistical significance".[18] [19] See Bayes factor for details..

Meta-criticism

The criticism here is of the application, or of the interpretation, rather than of the method. Attacks and defenses of the null-hypothesis significance test are collected in Harlow *et al.*.[20]

The original purposes of Fisher's formulation, as a tool for the experimenter, was to plan the experiment and to easily assess the information content of the small sample. There is little criticism, Bayesian in nature, of the formulation in its original context.

In other contexts, complaints focus on flawed interpretations of the results and over-dependence/emphasis on one test.

Numerous attacks on the formulation have failed to supplant it as a criterion for publication in scholarly journals. The most persistent attacks originated from the field of Psychology. After review, the American Psychological Association did not explicitly deprecate the use of null-hypothesis significance testing, but adopted enhanced publication guidelines which implicitly reduced the relative importance of such testing.

The International Committee of Medical Journal Editors recognizes an obligation to publish negative (not statistically significant) studies under some circumstances.

The applicability of the null-hypothesis testing to the publication of observational (as contrasted to experimental) studies is doubtful.

Philosophical criticism

Philosophical criticism to hypothesis testing includes consideration of borderline cases. Any process that produces a crisp decision from uncertainty is subject to claims of unfairness near the decision threshold. (Consider close election results.) The premature death of a laboratory rat during testing can impact doctoral theses and academic tenure decisions.

"... surely, God loves the .06 nearly as much as the .05"[21]

The statistical significance required for publication has no mathematical basis, but is based on long tradition.

"It is usual and convenient for experimenters to take 5% as a standard level of significance, in the sense that they are prepared to ignore all results which fail to reach this standard, and, by this means, to eliminate from further discussion the greater part of the fluctuations which chance causes have introduced into their experimental results."[5]

Ambivalence attacks all forms of decision making. A mathematical decision-making process is attractive because it is objective and transparent. It is repulsive because it allows authority to avoid taking personal responsibility for decisions.

Pedagogic criticism

Pedagogic criticism of the null-hypothesis testing includes the counter-intuitive formulation, the terminology and confusion about the interpretation of results.

"Despite the stranglehold that hypothesis testing has on experimental psychology, I find it difficult to imagine a less insightful means of transiting from data to conclusions."[22]

Students find it difficult to understand the formulation of statistical null-hypothesis testing. In rhetoric, examples often support an argument, but a mathematical proof "is a logical argument, not an empirical one". A single counterexample results in the rejection of a conjecture. Karl Popper defined science by its vulnerability to disproof by data. Null-hypothesis testing shares the mathematical and scientific perspective rather than the more familiar rhetorical one. Students expect hypothesis testing to be a statistical tool for illumination of the research hypothesis by the sample; it is not. The test asks indirectly whether the sample can illuminate the research hypothesis.

Students also find the terminology confusing. While Fisher disagreed with Neyman and Pearson about the theory of testing, their terminologies have been blended. The blend is not seamless or standardized. While this article teaches a pure Fisher formulation, even it mentions Neyman and Pearson terminology (Type II error and the alternative hypothesis). The typical introductory statistics text is less consistent. The Sage Dictionary of Statistics would not agree with the title of this article, which it would call null-hypothesis testing.[2] "...there is no alternate hypothesis in Fisher's scheme: Indeed, he violently opposed its inclusion by Neyman and Pearson."[23] In discussing test results, "significance" often has two distinct meanings in the same sentence; One is a probability, the other is a subject-matter measurement (such as currency). The significance (meaning) of (statistical) significance is significant (important).

There is widespread and fundamental disagreement on the interpretation of test results.

"A little thought reveals a fact widely understood among statisticians: The null hypothesis, taken literally (and that's the only way you can take it in formal hypothesis testing), is almost always false in the real world.... If it is false, even to a tiny degree, it must be the case that a large enough sample will produce a significant result and lead to its rejection. So if the null hypothesis is always false, what's the big deal about rejecting it?"[23] (The above criticism only applies to point hypothesis tests. If one were testing, for example, whether a parameter is greater than zero, it would not apply.)

"How has the virtually barren technique of hypothesis testing come to assume such importance in the process by which we arrive at our conclusions from our data?"[22]

Null-hypothesis testing just answers the question of "how well the findings fit the possibility that chance factors alone might be responsible."[2]

Null-hypothesis significance testing does not determine the truth or falsity of claims. It determines whether confidence in a claim based solely on a sample-based estimate exceeds a threshold. It is a research quality assurance test, widely used as one requirement for publication of experimental research with statistical results. It is uniformly agreed that statistical significance is not the only consideration in assessing the importance of research results. Rejecting the null hypothesis is not a sufficient condition for publication.

"Statistical significance does not necessarily imply practical significance!"[24]

Practical criticism

Practical criticism of hypothesis testing includes the sobering observation that published test results are often contradicted. Mathematical models support the conjecture that most published medical research test results are flawed. Null-hypothesis testing has not achieved the goal of a low error probability in medical journals.[25] [26]

Straw man

Hypothesis testing is controversial when the alternative hypothesis is suspected to be true at the outset of the experiment, making the null hypothesis the reverse of what the experimenter actually believes; it is put forward as a straw man only to allow the data to contradict it. Many statisticians have pointed out that rejecting the null hypothesis says nothing or very little about the likelihood that the null is true. Under traditional null hypothesis testing, the null is rejected when the conditional probability P(Data as or more extreme than observed | Null) is very small, say 0.05. However, some say researchers are really interested in the probability P(Null | Data as actually observed) which cannot be inferred from a p-value: some like to present these as inverses of each other but the events "Data as or more extreme than observed" and "Data as actually observed" are very different. In some cases , P(Null | Data) approaches 1 while P(Data as or more extreme than observed | Null) approaches 0, in other words, we can reject the null when it's virtually certain to be true. For this and other reasons, Gerd Gigerenzer has called null hypothesis testing "mindless statistics"[27] while Jacob Cohen described it as a ritual conducted to convince ourselves that we have the evidence needed to confirm our theories.[28]

Bayesian criticism

Bayesian statisticians reject classical null hypothesis testing, since it violates the Likelihood principle and is thus incoherent and leads to sub-optimal decision-making. The Jeffreys–Lindley paradox illustrates this. Along with many frequentist statisticians, Bayesians prefer to provide an estimate, along with a confidence interval, (although Bayesian confidence intervals are different from classical ones). Some Bayesians (James Berger in particular) have developed Bayesian hypothesis testing methods, though these are not accepted by all Bayesians (notably, Andrew Gelman). Given a prior probability distribution for one or more parameters, sample evidence can be used to generate an updated posterior distribution. In this framework, but *not* in the null hypothesis testing framework, it is meaningful to make statements of the general form "the probability that the true value of the parameter is greater than 0 is p". According to Bayes' theorem,

$$P(\text{Null}|\text{Data}) = P(\text{Data}|\text{Null})\frac{P(\text{Null})}{P(\text{Data})},$$

thus P(Null | Data) may approach 1 while P(Data | Null) approaches 0 only when P(Null)/P(Data) approaches infinity, i.e. (for instance) when the a priori probability of the null hypothesis, P(Null), is also approaching 1, while P(Data) approaches 0: then P(Data | Null) is low because the data are extremely unlikely, but the Null hypothesis is extremely likely to be true.

Publication bias

In 2002, a group of psychologists launched a new journal dedicated to experimental studies in psychology which support the null hypothesis. The *Journal of Articles in Support of the Null Hypothesis* [29] (JASNH) was founded to address a scientific publishing bias against such articles. According to the editors,

> "other journals and reviewers have exhibited a bias against articles that did not reject the null hypothesis. We plan to change that by offering an outlet for experiments that do not reach the traditional significance levels ($p < 0.05$). Thus, reducing the file drawer problem, and reducing the bias in psychological literature. Without such a resource researchers could be wasting their time examining empirical questions that have already been examined. We collect these articles and provide them to the scientific community free of cost."[30]

The "File Drawer problem" is a problem that exists due to the fact that academics tend not to publish results that indicate the null hypothesis could not be rejected. This does not mean that the relationship they were looking for did not exist, but it means they couldn't prove it. Even though these papers can often be interesting, they tend to end up unpublished, in "file drawers."

Ioannidis[26] has inventoried factors that should alert readers to the risks of publication bias.

Improvements

Jones and Tukey suggested a modest improvement in the original null-hypothesis formulation to formalize handling of one-tail tests.[31] They conclude that, in the "Lady Tasting Tea" example, Fisher ignored the 8-failure case (equally improbable as the 8-success case) in the example test involving tea, which altered the claimed significance by a factor of 2.

See also

- Comparing means test decision tree
- Complete spatial randomness
- Counternull
- Multiple comparisons
- Omnibus test

- Behrens–Fisher problem
- Bootstrapping (statistics)
- Checking if a coin is fair
- Falsifiability
- Fisher's method for combining independent tests of significance
- Modifiable Areal Unit Problem
- Null hypothesis
- P-value
- Representation theory
- Spatial autocorrelation
- Statistical theory
- Statistical significance
- Type I error, Type II error
- Exact test

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Statistical inference

Statistical inference is the process of drawing conclusions from data that are subject to random variation, for example, observational errors or sampling variation.[1] More substantially, the terms **statistical inference**, **statistical induction** and **inferential statistics** are used to describe systems of procedures that can be used to draw conclusions from datasets arising from systems affected by random variation.[2] Initial requirements of such a system of procedures for inference and induction are that the system should produce reasonable answers when applied to well-defined situations and that it should be general enough to be applied across a range of situations.

The outcome of statistical inference may be an answer to the question "what should be done next?", where this might be a decision about making further experiments or surveys, or about drawing a conclusion before implementing some organizational or governmental policy.

Introduction

Scope

For the most part, statistical inference makes propositions about populations, using data drawn from the population of interest via some form of random sampling. More generally, data about a random process is obtained from its observed behavior during a finite period of time. Given a parameter or hypothesis about which one wishes to make inference, statistical inference most often uses:

- a statistical model of the random process that is supposed to generate the data, and
- a particular realization of the random process; i.e., a set of data.

The conclusion of a **statistical inference** is a statistical proposition. Some common forms of statistical proposition are:

- an estimate; i.e., a particular value that best approximates some parameter of interest,
- a confidence interval (or set estimate); i.e., an interval constructed from the data in such a way that, under repeated sampling of datasets, such intervals would contain the true parameter value with the probability at the stated confidence level,
- a credible interval; i.e., a set of values containing, for example, 95% of posterior belief,
- rejection of an hypothesis [3]
- clustering or classification of data points into groups

Comparison to descriptive statistics

Statistical inference is generally distinguished from descriptive statistics. In simple terms, descriptive statistics can be thought of as being just a straightforward presentation of facts, in which modeling decisions made by a data analyst have had minimal influence. A complete statistical analysis will nearly always include both descriptive statistics and statistical inference, and will often progress in a series of steps where the emphasis moves gradually from description to inference.

Models/Assumptions

Any statistical inference requires some assumptions. A **statistical model** is a set of assumptions concerning the generation of the observed data and similar data. Descriptions of statistical models usually emphasize the role of population quantities of interest, about which we wish to draw inference.[4]

Degree of models/assumptions

Statisticians distinguish between three levels of modeling assumptions;

- **Fully parametric**: The probability distributions describing the data-generation process are assumed to be fully described by a family of probability distributions involving only a finite number of unknown parameters.[4] For example, one may assume that the distribution of population values is truly Normal, with unknown mean and variance, and that datasets are generated by 'simple' random sampling. The family of generalized linear models is a widely-used and flexible class of parametric models.
- **Non-parametric**: The assumptions made about the process generating the data are much less than in parametric statistics and may be minimal.[5] . For example, every continuous probability distribution has a median, which may be estimated using the sample median or the Hodges-Lehmann-Sen estimator, which has good properties when the data arise from simple random sampling.
- **Semi-parametric**: This term typically implies assumptions 'between' fully and non-parametric approaches. For example, one may assume that a population distribution have a finite mean. Furthermore, one may assume that the mean response level in the population depends in a truly linear manner on some covariate (a parametric assumption) but not make any parametric assumption describing the variance around that mean (i.e., about the presence or possible form of any heteroscedasticity). More generally, semi-parametric models can often be separated into 'structural' and 'random variation' components. One component is treated parametrically and the other non-parametrically. The well-known Cox model is a set of semi-parametric assumptions.

Importance of valid models/assumptions

Whatever level of assumption is made, correctly-calibrated inference in general requires these assumptions to be correct; i.e., that the data-generating mechanisms really has been correctly specified.

Incorrect assumptions of 'simple' random sampling can invalidate statistical inference [6] . More complex semi- and fully-parametric assumptions are also cause for concern. For example, incorrectly assuming the Cox model can in some cases lead to faulty conclusions [7] . Incorrect assumptions of Normality in the population also invalidates some forms of regression-based inference [8] . The use of **any** parametric model is viewed skeptically by most experts in sampling human populations: "most sampling statisticians, when they deal with confidence intervals at all, limit themselves to statements about [estimators] based on very large samples, where the central limit theorem ensures that these [estimators] will have distributions that are nearly normal."[9] Here, the central limit theorem states that the distribution of the sample mean "for very large samples" is approximately normally distributed, if the distribution is not heavy tailed.

Approximate distributions

Given the difficulty in specifying exact distributions of sample statistics, many methods have been developed for approximating these.

With finite samples, approximation results measure how close a limiting distribution approaches the statistic's sample distribution: For example, with 10,000 independent samples the normal distribution approximates (to two digits of accuracy) the distribution of the sample mean for many population distributions, by the Berry–Esseen theorem[10] . Yet for many practical purposes, the normal approximation provides a good approximation to the sample-mean's distribution when there are 10 (or more) independent samples, according to simulation studies, and statisticians' experience.[11] Following Kolmogorov's work in the 1950s, advanced statistics uses approximation theory and functional analysis to quantify the error of approximation: In this approach, the metric geometry of probability distributions is studied; this approach quantifies approximation error with, for example, the Kullback–Leibler distance, Bregman divergence, and the Hellinger distance.[12] [13] [14]

With infinite samples, limiting results like the central limit theorem describe the sample statistic's limiting distribution, if one exists. Limiting results are not statements about finite samples, and indeed are logically irrelevant to finite samples.[15] However, the asymptotic theory of limiting distributions is often invoked for work in estimation and testing. For example, limiting results are often invoked to justify the generalized method of moments and the use of generalized estimating equations, which are popular in econometrics and biostatistics. The magnitude of the difference between the limiting distribution and the true distribution (formally, the 'error' of the approximation) can be assessed using simulation:[16] . The use of limiting results in this way works well in many applications, especially with low-dimensional models with log-concave likelihoods (such as with one-parameter exponential families).

Randomization-based models

For a given dataset that was produced by a randomization design, the randomization distribution of a statistic (under the null-hypothesis) is defined by evauating the test statistic for all of the plans that could have been generated by the randomiation design. In frequentist inference, randomization allows inferences to be based on the randomization distribution rather than a subjective model, and this is important especially in survey sampling and design of experiments.[17] [18] . Statistical inference from randomized studies is also more straightforward than many other situations.[19] [20] [21] In Bayesian inference, randomization is also of importance: In survey sampling – sampling without replacement ensures the exchangeability of the sample with the population; in randomized experiments, randomization warrants a missing at random assumption for covariate information.[22]

Objective randomization allows properly inductive procedures.[23] [24] [25] [26] Many statisticians prefer randomization-based analysis of data that was generated by well-defined randomization procedures.[27] (However, it is true that in fields of science with developed theoretical knowledge and experimental control, randomized experiments may increase the costs of experimentation without improving the quality of inferences.[28] [29]) Similarly, results from randomized experiments are recommended by leading statistical authorities as allowing inferences with greater reliability than do observational studies of the same phenomena.[30] However, a good observational study may be better than a bad randomized experiment.

The statistical analysis of a randomized experiment may be based on the randomization scheme stated in the experimental protocol and does not need a subjective model.[31] [32]

However, not all hypotheses can be tested by randomized experiments or random samples, which often require a large budget, a lot of expertise and time, and may have ethical problems.

Model-based analysis of randomized experiments

It is standard practice to refer to a statistical model, often a normal linear model, when analyzing data from randomized experiments. However, the randomization scheme guides the choice of a statistical model. It is not possible to choose an appropriate model without knowing the randomization scheme.[18] Seriously misleading results can be obtained analyzing data from randomized experiments while ignoring the experimental protocol; common mistakes include forgetting the blocking used in an experiment and confusing repeated measurements on the same experimental unit with independent replicates of the treatment applied to different experimental units.[33]

Modes of inference

Different schools of statistical inference have become established. These schools (or 'paradigms') are not mutually-exclusive, and methods which work well under one paradigm often have attractive interpretations under other paradigms. The two main paradigms in use are frequentist and Bayesian inference, which are both summarized below.

Frequentist inference

This paradigm calibrates the production of propositions by considering (notional) repeated sampling of datasets similar to the one at hand. By considering its characteristics under repeated sample, the frequentist properties of any statistical inference procedure can be described - although in practice this quantification may be challenging.

Examples of frequentist inference

- P-value
- Confidence interval

Frequentist inference, objectivity, and decision theory

Frequentist inference calibrates procedures, such as tests of hypothesis and constructions of confidence intervals, in terms of frequency probability; that is, in terms of repeated sampling from a population. (In contrast, Bayesian inference calibrates procedures with regard to epistemological uncertainty, described as a probability measure)

The frequentist calibration of procedures can be done without regard to utility functions. However, some elements of frequentist statistics, such as statistical decision theory, do incorporate utility functions. In particular, frequentist developments of optimal inference (such as minimum-variance unbiased estimators, or uniformly most powerful testing) make use of loss functions, which play the role of (negative) utility functions. Loss functions must be explicitly stated for statistical theorists to prove that a statistical procedure has an optimality property. For example, median-unbiased estimators are optimal under absolute value loss functions, and least squares estimators are optimal under squared error loss functions.

While statisticians using frequentist inference must choose for themselves the parameters of interest, and the estimators/test statistic to be used, the absence of obviously-explicit utilities and prior distributions has helped frequentist procedures to become widely-viewed as 'objective'.

Bayesian inference

The Bayesian calculus describes degrees of belief using the 'language' of probability; beliefs are positive, integrate to one, and obey probability axioms. Bayesian inference uses the available posterior beliefs as the basis for making statistical propositions. There are several different justifications for using the Bayesian approach.

Examples of Bayesian inference

- Credible intervals for interval estimation
- Bayes factors for model comparison

Bayesian inference, subjectivity and decision theory

Many informal Bayesian inferences are based on "intuitively reasonable" summaries of the posterior. For example, the posterior mean, median and mode, highest posterior density intervals, and Bayes Factors can all be motivated in this way. While a user's utility function need not be stated for this sort of inference, these summaries do all depend (to some extent) on stated prior beliefs, and are generally viewed as subjective conclusions. (Methods of prior construction which do not require external input have been proposed but not yet fully developed.)

Formally, Bayesian inference is calibrated with reference to an explicitly stated utility, or loss function; the 'Bayes rule' is the one which maximizes expected utility, averaged over the posterior uncertainty. Formal Bayesian inference therefore automatically provides optimal decisions in a decision theoretic sense. Given assumptions, data and utility, Bayesian inference can be made for essentially any problem, although not every statistical inference need have a Bayesian interpretation. Analyses which are not formally Bayesian can be (logically) incoherent; a feature of Bayesian procedures which use proper priors (i.e., those integrable to one) is that they are guaranteed to be coherent. Some advocates of Bayesian inference assert that inference *must* take place in this decision-theoretic framework, and that Bayesian inference should not conclude with the evaluation and summarization of posterior beliefs.

Other modes of inference (besides frequentist and Bayesian)

Information and computational complexity

Other forms of statistical inference have been developed from ideas in information theory [34] and the theory of Kolmogorov complexity.[35] . For example, the minimum description length (MDL) principle selects statistical models that maximally compress the data; inference proceeds without assuming counterfactual or non-falsifiable 'data-generating mechanisms' or probability models for the data, as might be done in frequentist or Bayesian approaches.

However, if a 'data generating mechanism' does exist in reality, then according to Shannon's source coding theorem it provides the MDL description of the data, on average and asymptotically[36] . In minimizing description length (or descriptive complexity), MDL estimation is similar to maximum likelihood estimation and maximum a posteriori estimation (using maximum-entropy Bayesian priors). However, MDL avoids assuming that the underlying probability model is known; the MDL principle can also be applied without assumptions that e.g. the data arose from independent sampling[36] [37] . The MDL principle has been applied in communication-coding theory in information theory, in linear regression, and in time-series analysis (particularly for chosing the degrees of the polynomials in Autoregressive moving average (ARMA) models).[37]

Information-theoretic statistical inference has been popular in data mining, which has become a common approach for very large observational and heterogeneous datasets made possible by the computer revolution and internet[35] .

The evaluation of statistical inferential procedures often uses techniques or criteria from computational complexity theory or numerical analysis.[38]

Fiducial inference

Fiducial inference was an approach to statistical inference based on fiducial probability, also known as a "fiducial distribution". In subsequent work, this approach has been recognized as being ill-defined, extremely limited in applicability, and even fallacious.[39]

Structural inference

Developing ideas of Fisher and of Pitman from 1938-1939[40] , George A. Barnard developed "structural inference" or "pivotal inference",[41] an approach using invariant probabilities on group families. Barnard reformulated the arguments behind fiducial inference on a restricted class of models on which "fiducial" procedures would be well-defined and useful.

Inference topics

The topics below are usually included in the area of **statistical inference**.

1. Statistical assumptions
2. Statistical decision theory
3. Estimation theory
4. Statistical hypothesis testing
5. Revising opinions in statistics
6. Design of experiments, the analysis of variance, and regression
7. Survey sampling
8. Summarizing statistical data

See also

- Predictive inference
- Induction (philosophy)
- Philosophy of statistics
- Algorithmic inference

Notes

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[2] Dodge, Y. (2003) *The Oxford Dictionary of Statistical Terms*, OUP. ISBN 0-19-920613-9 (entry for "inferential statistics")

[3] According to Peirce, acceptance means that inquiry on this question ceases for the time being. In science, all scientific theories are revisable

[4] Cox (2006) page 2

[5] van der Vaart, A.W. (1998) *Asymptotic Statistics* Cambridge University Press. ISBN 0-521-78450-6 (page 341)

[6] Kruskal, William (December 1988). "Miracles and Statistics: The Casual Assumption of Independence (ASA Presidential address)" (http://www.jstor.org/stable/2290117). *Journal of the American Statistical Association* **83** (404): 929–940. . JSTOR 2290117

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[8] Berk, R. (2003) *Regression Analysis: A Constructive Critique (Advanced Quantitative Techniques in the Social Sciences) (v. 11)* Sage Publications. ISBN 0-761-92904-5

[9] Page 6 in Brewer, Ken (2002). *Combined Survey Sampling Inference: Weighing of Basu's Elephants*. Hodder Arnold. ISBN 0340692294, 978-0340692295.: In particular, a normal distribution "would be a totally unrealistic and catastraphoicaly unwise assumption to make if we were dealing with any kind of economic population" (page 6 again).

[10] Jörgen Hoffman-Jörgensen's *Probability With a View Towards Statistics*, Volume I. Page 399

[11] Op. cit.

[12] Lucien Le Cam. *Asymptotic Methods of Statistical Decision Theory*.

[13] Erik Torgerson (1991) *Comparison of Statistical Experiments*, volume 36 of Encyclopedia of Mathematics. Cambridge University Press.

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[15] Kolmogorov, Andrei N. (1963). "On Tables of Random Numbers". *Sankhyā Ser. A.* **25**: 369–375. (Page 369): "The frequency concept, based on the notion of limiting frequency as the number of trials increases to infinity, does not contribute anything to substantiate the applicability of the results of probability theory to real practical problems where we have always to deal with a finite number of trials". (page 369)
Lucien Le Cam. *Asymptotic Methods of Statistical Decision Theory*: "Indeed, limit theorems 'as n tends to infinity' are logically devoid of content about what happens at any particular n . All they can do is suggest [definite] approaches whose performance must then be checked on the case at hand." (page xiv)
Pfanzagl, Johann; with the assistance of R. Hamböker (1994). *Parametric Statistical Theory*. Walter de Gruyter. MR1291393. ISBN 3-11-01-3863-8.: "The crucial drawback of asymptotic theory: What we [wish] from asymptotic theory are results which hold approximately . . . . What asymptotic theory has to offer are limit theorems."(page ix) "What counts for applications are approximations, not limits." (page 188)

[16] Pfanzagl, Johann; with the assistance of R. Hamböker (1994). *Parametric Statistical Theory*. Walter de Gruyter. MR1291393. ISBN 3-11-01-3863-8.: "By taking a limit theorem as being approximately true for large sample sizes, we commit an error the size of which is unknown. [. . .] Realistic information about the remaining errors may be obtained by simulations." (page ix)

[17] Jerzy Neyman. "On the Two Different Aspects of the Representative Method: The Method of Stratified Sampling and the Method of Purposive Selection" given at the Royal Statistical Society on 19 June 1934.
[18] Hinkelmann and Kempthorne.
[19] ASA Guidelines for a first course in statistics for non-statisticians. (available at the ASA website)
[20] David A. Freedman et alia's *Statistics*.
[21] David S. Moore and George McCabe. *Introduction to the Practice of Statistics.*
[22] Gelman, Rubin. *Bayesian Data Analysis*.
[23] Peirce (1877-1878)
[24] Peirce (1883)
[25] David Freedman et alia *Statistics* and David A. Freedman *Statistical Models*.
[26] Rao, C.R. (1997) *Statistics and Truth: Putting Chance to Work*, World Scientific. ISBN 9810231113
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[28] Box, G.E.P. and Friends (2006) *Improving Almost Anything: Ideas and Essays, Revised Edition*, Wiley. ISBN 978-0-471-72755-2
[29] Cox (2006), page 196
[30] ASA Guidelines for a first course in statistics for non-statisticians. (available at the ASA website)

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[32] Hinkelmann, Klaus and Kempthorne, Oscar (2008). *Design and Analysis of Experiments, Volume I: Introduction to Experimental Design* (http://books.google.com/books?id=T3wWj2kVYZgC&printsec=frontcover&hl=sv&source=gbs_book_other_versions_r&cad=4_0) (Second ed.). Wiley (http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0471727563.html). ISBN 978-0-471-72756-9.
[33] Hinkelmann and Kempthorne, chapter 6. Bailey, etc.
[34] Soofi (2000)
[35] Hansen & Yu (2001)
[36] Hansen and Yu (2001), page 747.
[37] Rissanen (1989), page 84
[38] Joseph F. Traub, G. W. Wasilkowski, and H. Wozniakowski. Judin and Nemirovski.
[39] Neyman 1956. Zabell.
[40] Davison, op. cit. page 12.
[41] Barnard, G.A. (1995) "Pivotal Models and the Fiducial Argument", International Statistical Review, 63 (3), 309–323. Stable URL: http://www.jstor.org/stable/1403482

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External links

- MIT OpenCourseWare (http://ocw.mit.edu/OcwWeb/Mathematics/18-441Statistical-InferenceSpring2002/CourseHome/): Statistical Inference

Syllogism

A **syllogism** (Greek: συλλογισμός – *syllogismos* – "conclusion," "inference") or **logical appeal** is a kind of logical argument in which one proposition (the conclusion) is inferred from two others (the premises) of a certain form.

In *Prior Analytics,* Aristotle defines syllogism as "a discourse in which, certain things having been supposed, something different from the things supposed results of necessity because these things are so." (24b18–20)

Despite this very general definition, he limits himself first to categorical syllogisms[1] (and later to modal syllogisms). The syllogism was at the core of traditional deductive reasoning, where facts are determined by combining existing statements, in contrast to inductive reasoning where facts are determined by repeated observations. The syllogism was superseded by first-order predicate logic following the work of Gottlob Frege, in particular his Begriffsschrift (Concept Script)(1879).

Basic structure

A categorical syllogism consists of three parts: the major premise, the minor premise and the conclusion.

Each part is a categorical proposition, and each categorical position contains two categorical terms.[2] In Aristotle, each of the premises is in the form "All A are B," "Some A are B", "No A are B" or "Some A are not B", where "A" is one term and "B" is another. More modern logicians allow some variation. Each of the premises has one term in common with the conclusion: in a major premise, this is the *major term* (*i.e.,* the predicate of the conclusion); in a minor premise, it is the *minor term* (the subject) of the conclusion. For example:

> Major premise: All men are mortal.
>
> Minor premise: Socrates is a man.
>
> Conclusion: Socrates is mortal.

Each of the three distinct terms represents a category. In this example, "men," "mortal," and "Socrates." "Mortal" is the major term; "Socrates", the minor term. The premises also have one term in common with each other, which is known as the *middle term*; in this example, "man." Here the major premise is universal and the minor particular, but this need not be so. For example:

> Major premise: All mortals die.
>
> Minor premise: All men are mortals.
>
> Conclusion: All men die.

Here, the major term is "die", the minor term is "men," and the middle term is "mortals". Both of the premises are universal.

A sorites is a form of argument in which a series of incomplete syllogisms is so arranged that the predicate of each premise forms the subject of the next until the subject of the first is joined with the predicate of the last in the conclusion. For example, if one argues that a given number of grains of sand does not make a heap and that an additional grain does not either, then to conclude that no additional amount of sand will make a heap is to construct a sorites argument.

Types of syllogism

Although there are infinitely many possible syllogisms, there are only a finite number of logically distinct types. We shall classify and enumerate them below. Note that the syllogism above has the abstract form:

Major premise: All M are P.

Minor premise: All S are M.

Conclusion: All S are P.

The premises and conclusion of a syllogism can be any of four types, which are labeled by letters[3] as follows. The meaning of the letters is given by the table:

code	*quantifier*	*subject*	*copula*	*predicate*	*type*	*example*
a	All	S	are	P	universal affirmatives	All humans are mortal.
e	No	S	are	P	universal negatives	No humans are perfect.
i	Some	S	are	P	particular affirmatives	Some humans are healthy.
o	Some	S	are not	P	particular negatives	Some humans are not clever.

(See Square of opposition for a discussion of the logical relationships between these types of propositions.)

In Analytics, Aristotle mostly uses the letters A, B and C as term place holders, rather than giving concrete examples, an innovation at the time. It is traditional to use *is* rather than *are* as the copula, hence *All A is B* rather than *All As are Bs* It is traditional and convenient practice to use a,e,i,o as infix operators to enable the categorical statements to be written succinctly thus:

Form	**Shorthand**
All A is B	AaB
No A is B	AeB
Some A is B	AiB
Some A is not B	AoB

This particular syllogistic form is dubbed BARBARA (see below) and can be written neatly as BaC,AaB -> AaC.

The letter S is the subject of the conclusion, P is the predicate of the conclusion, and M is the middle term. The major premise links M with P and the minor premise links M with S. However, the middle term can be either the subject or the predicate of each premise where it appears. The differing positions of the major, minor, and middle terms gives rise to another classification of syllogisms known as the *figure*. Given that in each case the conclusion is S-P, the four figures are:

	Figure 1	*Figure 2*	*Figure 3*	*Figure 4*
Major premise:	M–P	P–M	M–P	P–M
Minor premise:	S–M	S–M	M–S	M–S

Putting it all together, there are 256 possible types of syllogisms (or 512 if the order of the major and minor premises is changed, although this makes no difference logically). Each premise and the conclusion can be of type A, E, I or O, and the syllogism can be any of the four figures. A syllogism can be described briefly by giving the letters for the premises and conclusion followed by the number for the figure. For example, the syllogism BARBARA above is AAA-1, or "A-A-A in the first figure".

The vast majority of the 256 possible forms of syllogism are invalid (the conclusion does not follow logically from the premises). The table below shows the valid forms. Even some of these are sometimes considered to commit the existential fallacy, meaning they are invalid if they mention an empty category. These controversial patterns are marked in italics.

Figure 1	*Figure 2*	*Figure 3*	*Figure 4*
Barbara	Cesare	*Darapti*	*Bramantip*
Celarent	Camestres	Disamis	Camenes
Darii	Festino	Datisi	Dimaris
Ferio	Baroco	*Felapton*	*Fesapo*
		Bocardo	Fresison
		Ferison	

The letters A, E, I, O have been used since the medieval Schools to form mnemonic names for the forms as follows: 'Barbara' stands for AAA, 'Celarent' for EAE, etc.

A sample syllogism of each type follows. Next to the name, the mood and figure of each syllogism appears (e.g., EIO-3 next to Ferison).

Next to each premise and conclusion is a shorthand description of the sentence. So in AAI-3, the premise "All fruit is nutritious" becomes "(MaP)"; the symbols mean that the first term ("fruit") is the middle term, the second term ("nutritious") is the predicate of the conclusion, and the relationship between the two terms is labeled "A" (All M are S).

Barbara (AAA-1)

All animals are mortal. (MaP)

All men are animals. (SaM)

All men are mortal. (SaP)

Celarent (EAE-1)

No reptiles have fur. (MeP)

All snakes are reptiles. (SaM)

No snakes have fur. (SeP)

Darii (AII-1)

All kittens are playful. (MaP)

Some pets are kittens. (SiM)

Some pets are playful. (SiP)

Ferio (EIO-1)

No homework is fun. (MeP)

Some reading is homework. (SiM)

Some reading is not fun. (SoP)

Cesare (EAE-2)

No healthful food is fattening. (PeM)

All cakes are fattening. (SaM)

No cakes are healthful food. (SeP)

Camestres (AEE-2)

All horses have hooves. (PaM)

No humans have hooves. (SeM)

No humans are horses. (SeP)

Festino (EIO-2)

No lazy students are students who pass exams. (PeM)

Some students are students who pass exams. (SiM)

Some students are not lazy students. (SoP)

Baroco (AOO-2)

All informative things are useful things. (PaM)

Some websites are not useful things. (SoM)

Some websites are not informative. (SoP)

Darapti (AAI-3)

All fruit is nutritious. (MaP)

All fruit is tasty. (MaS)

Some tasty things are nutritious. *(SiP)*

Disamis (IAI-3)

Some mugs are beautiful. (MiP)

All mugs are useful things. (MaS)

Some useful things are beautiful. (SiP)

Datisi (AII-3)

All the industrious boys in this school have red hair. (MaP)

Some of the industrious boys in this school are boarders. (MiS)

Some boarders in this school have red hair. (SiP)

Felapton (EAO-3)

No jug in this cupboard is new. (MeP)

All jugs in this cupboard are cracked. (MaS)

Some of the cracked items in this cupboard are not new. *(SoP)*

Bocardo (OAO-3)

Some cats have no tails. (MoP)

All cats are mammals. (MaS)

Some mammals have no tails. (SoP)

Ferison (EIO-3)

No tree is edible. (MeP)

Some trees are green things. (MiS)

Some green things are not edible. (SoP)

Bramantip (AAI-4)

All apples in my garden are wholesome fruit. (PaM)

All wholesome fruit is ripe fruit. (MaS)

Some ripe fruit are apples in my garden. *(SiP)*

Camenes (AEE-4)

All coloured flowers are scented flowers. (PaM)

No scented flowers are grown indoors. (MeS)

No flowers grown indoors are coloured flowers. (SeP)

Dimaris (IAI-4)

Some small birds are birds that live on honey. (PiM)

All birds that live on honey are colourful birds. (MaS)

Some colourful birds are small birds. (SiP)

Fesapo (EAO-4)

No humans are perfect creatures. (PeM)

All perfect creatures are mythical creatures. (MaS)

Some mythical creatures are not human. *(SoP)*

Fresison (EIO-4)

No competent people are people who always make mistakes. (PeM)

Some people who always make mistakes are people who work here. (MiS)

Some people who work here are not competent people. (SoP)

Forms can be converted to other forms, following certain rules.

Terms in syllogism

We may, with Aristotle, distinguish **singular** terms such as *Socrates* and **general** terms such as *Greeks*. Aristotle further distinguished (a) terms that could be the subject of predication, and (b) terms that could be predicated of others by the use of the copula (is are). (Such a predication is known as a distributive as opposed to non-distributive as in *Greeks are numerous*. It is clear that Aristotle's syllogism works only for distributive predication for we cannot reason *All Greeks are Animals, Animals are numerous, therefore All Greeks are numerous*.) In Aristotle's view singular terms were of type (a) and general terms of type (b). Thus *Men* can be predicated of *Socrates* but *Socrates* cannot be predicated of anything. Therefore to enable a term to be interchangeable — that is to be either in the subject or predicate position of a proposition in a syllogism — the terms must be general terms, or categorical terms as they came to be called. Consequently the propositions of a syllogism should be categorical propositions (both terms general) and syllogism employing just categorical terms came to be called categorical syllogisms.

It is clear that nothing would prevent a singular term occurring in a syllogism — so long as it was always in the subject position — however such a syllogism, even if valid, would not be a categorical syllogism. An example of such would be *Socrates is a man, All men are mortal, therefore Socrates is mortal.* Intuitively this is as valid as *All Greeks are men, all men are mortal therefore all Greeks are mortals*. To argue that its validity can be explained by the theory of syllogism it would be necessary to show that *Socrates is a man* is the equivalent of a categorical proposition. It can be argued *Socrates is a man* is equivalent to *All that are identical to Socrates are men*, so our non-categorical syllogism can be justified by use of the equivalence above and then citing BARBARA.

Existential import

If a statement includes a term so that the statement is false if the term has no instances (is not instantiated) then the statement is said to entail existential import with respect to that term. In particular, a universal statement of the form *All A is B* has existential import with respect to A if *All A is B* is false if there are no As.

The following problems arise:

(a) In natural language and normal use, which statements of the forms All A is B, No A is B, Some A is B and Some A is not B have existential import and with respect to which terms?

(b) In the four forms of categorical statements used in syllogism, which statements of the form AaB, AeB, AiB and AoB have existential import and with respect to which terms?

(c) What existential imports must the forms AaB, AeB, AiB and AoB have for the square of opposition be valid?

(d) What existential imports must the forms AaB, AeB, AiB and AoB to preserve the validity of the traditionally valid forms of syllogisms?

(e) Are the existential imports required to satisfy (d) above such that the normal uses in natural languages of the forms All A is B, No A is B, Some A is B and Some A is not B are intuitively and fairly reflected by the categorical statements of forms Ahab, Abe, Ail and Alb?

For example, if it is accepted that AiB is false if there are no As and AaB entails AiB, then AiB has existential import with respect to A, and so does AaB. Further, if it is accepted that AiB entails BiA, then AiB and AaB have existential import with respect to B as well. Similarly, if AoB is false if there are no As, and AeB entails AoB, and AeB entails BeA (which in turn entails BoA) then both AeB and AoB have existential import with respect to both A and B. It follows immediately that all universal categorical statements have existential import with respect to both terms. If AaB and AeB is a fair representation of the use of statements in normal natural language of All A is B and No A is B respectively, then the following example consequences arise:

"All flying horses are mythological" is false if there are not flying horses.

If "No men are fire-eating rabbits" is true, then "There are fire-eating dragons" is false.

and so on.

If it is ruled that no universal statement has existential import then the square of opposition fails in several respects (e.g. AaB does not entail AiB) and a number of syllogisms are no longer valid (e.g. BaC,AaB->AiC).

These problems and paradoxes arise in both natural language statements and statements in syllogism form because of ambiguity, in particular ambiguity with respect to All. If "Fred claims all his books were Pulitzer Prize winners", is Fred claiming that he wrote any books? If not, then is what he claims true? Suppose Jane says none of her friends are poor; is that true if she has no friends? The first-order predicate calculus avoids the problems of such ambiguity by using formulae that carry no existential import with respect to universal statements; existential claims have to be explicitly stated. Thus natural language statements of the forms All A is B, No A is B, Some A is B and Some A is not B can be exactly represented in first order predicate calculus in which any existential import with respect to terms A and/or B is made explicitly or not made at all. Consequently the four forms AaB, AeB, AiB and AoB can be represented in first order predicate in every combination of existential import, so that it can establish which construal, if any, preserves the square of opposition and the validly of the traditionally valid syllogism. Strawson claims that such a construal is possible, but the results are such that, in his view, the answer to question (a) above is *no*.

Syllogism in the history of logic

Syllogism dominated Western philosophical thought until The Age of Enlightenment in the 17th Century. At that time, Sir Francis Bacon rejected the idea of syllogism and deductive reasoning by asserting that it was fallible and illogical[4] . Bacon offered a more inductive approach to logic in which experiments were conducted and axioms were drawn from the observations discovered in them.

In the 19th Century, modifications to syllogism were incorporated to deal with disjunctive ("A or B") and conditional ("if A then B") statements. Kant famously claimed that logic was the one completed science, and that Aristotelian logic more or less included everything about logic there was to know. Though there were alternative systems of logic such as Avicennian logic or Indian logic elsewhere, Kant's opinion stood unchallenged in the West until 1879 when Frege published his Begriffsschrift (Concept Script). This introduced a calculus, a method of representing categorical statements — and statements that are not provided for in syllogism as well — by the use of quantifiers and variables.

This led to the rapid development of sentential logic and first-order predicate logic, subsuming syllogistic reasoning, which was, therefore, after 2000 years, suddenly considered obsolete by many. The Aristotelian system is explicated in modern fora of academia primarily in introductory material and historical study.

One notable exception to this modern relegation, however, is the continued application of the intricate rules of Aristotelian logic, as taught by St. Thomas Aquinas, in the Roman Curia's Congregation for the Doctrine of the Faith, and the Apostolic Tribunal of the Roman Rota.

Everyday syllogistic mistakes

People often make mistakes when reasoning syllogistically.[5]

For instance, from the premises some A are B, some B are C, people tend to come to a definitive conclusion that therefore some A are C.[6] However, this does not follow according to the rules of classical logic. For instance, while some cats (A) are black (B), and some black things (B) are televisions (C), it does not follow from the parameters that some cats (A) are televisions (C). This is because first, the mood of the syllogism invoked is illicit (III), and second, the supposition of the middle term is variable between that of the middle term in the major premise, and that of the middle term in the minor premise (not all "some" cats are by necessity of logic the same "some black things").

Determining the validity of a syllogism involves determining the distribution of each term in each statement, meaning whether all members of that term are accounted for.

In simple syllogistic patterns, the fallacies of invalid patterns are:

> Undistributed middle - Neither of the premises accounts for all members of the middle term, which consequently fails to link the major and minor term.
>
> Illicit treatment of the major term - The conclusion implicates all members of the major term (P — meaning the proposition is negative); however, the major premise does not account for them all (i e P is either an affirmative predicate or a particular subject there).
>
> Illicit treatment of the minor term - Same as above, but for the minor term (S — meaning the proposition is universal) and minor premise (where S is either a particular subject or an affirmative predicate).
>
> Exclusive premises - Both premises are negative, meaning no link is established between the major and minor terms.
>
> Affirmative conclusion from a negative premise - If either premise is negative, the conclusion must also be.
>
> Existential fallacy - This is a more controversial one. If both premises are universal, i.e. "All" or "No" statements, one school of thought says they do not imply the existence of any members of the terms. In this case, the conclusion cannot be existential; i.e. beginning with "Some". Another school of thought says that affirmative statements (universal or particular) do imply the subject's existence, but negatives do not. A third school of thought says that the any type of proposition may or may not involve the subject's existence, and

although this may condition the conclusion it does not affect the form of the syllogism.

See also

- Enthymeme
- Forms of syllogism:
  - Disjunctive syllogism
  - Hypothetical syllogism
  - Polysyllogism
  - Prosleptic syllogism
  - Quasi-syllogism
  - Statistical syllogism
- Syllogistic fallacy
- The False Subtlety of the Four Syllogistic Figures
- Venn diagram

Notes

[1] "Philosophical Dictionary: Caird-Catharsis" (http://www.philosophypages.com/dy/c.htm#capro). Philosophypages.com. 2002-08-08. . Retrieved 2009-12-14.

[2] "Philosophical Dictionary: Caird-Catharsis" (http://www.philosophypages.com/dy/c.htm#capro). Philosophypages.com. 2002-08-08. . Retrieved 2009-12-14.

[3] According to Copi, p. 127: 'The letter names are presumed to come from the Latin words "***A***ff***I***rmo" and "n***E***g***O***," which mean "I affirm" and "I deny," respectively; the first capitalized letter of each word is for universal, the second for particular'

[4] Bacon, Francis. *The Great Instauration*, 1620

[5] See, e.g., Evans, J. St. B. T (1989). *Bias in human reasoning*. London: LEA.

[6] See the meta-analysis by Chater, N. & Oaksford, M. (1999). The Probability Heuristics Model of Syllogistic Reasoning. *Cognitive Psychology*, *38*, 191-258.

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External links

- Aristotle's Logic (http://plato.stanford.edu/entries/aristotle-logic) entry by Robin Smith in the *Stanford Encyclopedia of Philosophy*
- The Traditional Square of Opposition (http://plato.stanford.edu/entries/square) entry by Terence Parsons in the *Stanford Encyclopedia of Philosophy*
- Medieval Theories of the Syllogism (http://plato.stanford.edu/entries/medieval-syllogism) entry by Henrik Lagerlund in the *Stanford Encyclopedia of Philosophy*
- Aristotle's Prior Analytics: the Theory of Categorical Syllogism (http://www.ontology.co/aristotle-syllogism-categorical.htm) an annotated bibliography on Aristotle's syllogistic
- Abbreviatio Montana (http://www.humanities.mq.edu.au/Ockham/x52t06.html) article by Prof. R. J. Kilcullen of Macquarie University on the medieval classification of syllogisms.
- The Figures of the Syllogism (http://www.multicians.org/thvv/petrus-hispanius.html) is a brief table listing the forms of the syllogism.
- www.fibonicci.co.uk/syllogisms (http://www.fibonicci.co.uk/syllogisms) some fun syllogism tests/quizzes
- Syllogistic Reasoning in Buddhism - Example & Worksheet (http://www.understandingthemind.org/syllogism.pdf)

Theory

In philosophy, **theory** (from ancient Greek *theoria*, θεωρία, meaning "a looking at, viewing, beholding") refers to contemplation or speculation, as opposed to action.[1] Theory is especially often contrasted to "practice" (Greek *praxis*, πρᾶξις) a concept that in its original Aristotelian context referred to actions done for their own sake, but can also refer to "technical" actions instrumental to some other aim, such as the making of tools or houses. "Theoria" is also a word still used in theological contexts.

A classical example uses the discipline of medicine to explain the distinction: Medical theory and theorizing involves trying to understand the causes and nature of health and sickness, while the practical side of medicine is trying to make people healthy. These two things are related but can be independent, because it is possible to research health and sickness without curing specific patients, and it is possible to cure a patient without knowing how the cure worked.[2]

The word θεωρία apparently developed special uses early in the Greek language. In the book, *From Religion to Philosophy*, Francis Cornford suggests that the Orphics used the word "theory" to mean 'passionate sympathetic contemplation'.[3] Pythagoras changed the word to mean a passionate sympathetic contemplation of mathematical and scientific knowledge. This was because Pythagoras considered such intellectual pursuits the way to reach the highest plane of existence. Pythagoras emphasized subduing emotions and bodily desires in order to enable the intellect to function at the higher plane of theory. Thus it was Pythagoras who gave the word "theory" the specific meaning which leads to the classical and modern concept of a distinction between theory as uninvolved, neutral thinking, and practice.[4]

While theories in the arts and philosophy may address ideas and not easily observable empirical phenomena, in modern science the term "theory", or "scientific theory" is generally understood to refer to a proposed explanation of empirical phenomena, made in a way consistent with the scientific method. Such theories are preferably described in such a way that any scientist in the field is in a position to understand, verify, and challenge (or "falsify") it. In this modern scientific context the distinction between theory and practice corresponds roughly to the distinction between theoretical science and technology or applied science.

Theories formally and generally

Theories are analytical tools for understanding, explaining, and making predictions about a given subject matter. There are theories in many and varied fields of study, including the arts and sciences. A formal theory is syntactic in nature and is only meaningful when given a semantic component by applying it to some content (i.e. facts and relationships of the actual historical world as it is unfolding). Theories in various fields of study are expressed in natural language, but are always constructed in such a way that their general form is identical to a theory as it is expressed in the formal language of mathematical logic. Theories may be expressed mathematically, symbolically, or in common language, but are generally expected to follow principles of rational thought or logic.

Theory is constructed of a set of sentences which consist entirely of true statements about the subject matter under consideration. However, the truth of any one of these statements is always relative to the whole theory. Therefore the same statement may be true with respect to one theory, and not true with respect to another. This is, in ordinary language, where statements such as "He is a terrible person" cannot be judged to be true or false without reference to some interpretation of who "He" is and for that matter what a "terrible person" is under the theory. [5]

Sometimes two theories have exactly the same explanatory power because they make the same predictions. A pair of such theories is called indistinguishable, and the choice between them reduces to convenience or philosophical preference.

The form of theories is studied formally in mathematical logic, especially in model theory. When theories are studied in mathematics, they are usually expressed in some formal language and their statements are closed under application of certain procedures called rules of inference. A special case of this, an axiomatic theory, consists of axioms (or axiom schemata) and rules of inference. A theorem is a statement that can be derived from those axioms by application of these rules of inference. Theories used in applications are abstractions of observed phenomena and the resulting theorems provide solutions to real-world problems. Obvious examples include arithmetic (abstracting concepts of number), geometry (concepts of space), and probability (concepts of randomness and likelihood).

Gödel's incompleteness theorem shows that no consistent, recursively enumerable theory (that is, one whose theorems form a recursively enumerable set) in which the concept of natural numbers can be expressed, can include all true statements about them. As a result, some domains of knowledge cannot be formalized, accurately and completely, as mathematical theories. (Here, formalizing accurately and completely means that all true propositions—and only true propositions—are derivable within the mathematical system.) This limitation, however, in no way precludes the construction of mathematical theories that formalize large bodies of scientific knowledge.

Underdetermination

A theory is *underdetermined* (also called *indeterminacy of data to theory*) if, given the available evidence cited to support the theory, there is a rival theory which is inconsistent with it that is at least as consistent with the evidence. Underdetermination is an epistemological issue about the relation of evidence to conclusions.

Intertheoretic reduction and elimination

If there is a new theory which is better at explaining and predicting phenomena than an older theory (i.e. it has more explanatory power), we are justified in believing that the newer theory describes reality more correctly. This is called an *intertheoretic reduction* because the terms of the old theory can be reduced to the terms of the new one. For instance, our historical understanding about "sound," "light" and "heat" have today been reduced to "wave compressions and rarefactions," "electromagnetic waves," and "molecular kinetic energy," respectively. These terms which are identified with each other are called *intertheoretic identities.* When an old theory and a new one are parallel in this way, we can conclude that we are describing the same reality, only more completely.

In cases where a new theory uses new terms which do not reduce to terms of an older one, but rather replace them entirely because they are actually a misrepresentation it is called an *intertheoretic elimination.* For instance, the obsolete scientific theory that put forward an understanding of heat transfer in terms of the movement of caloric fluid was eliminated when a theory of heat as energy replaced it. Also, the theory that phlogiston is a substance released from burning and rusting material was eliminated with the new understanding of the reactivity of oxygen.

Theories vs. theorems

Theories are distinct from theorems: theorems are derived deductively from theories according to a formal system of rules, generally as a first step in testing or applying the theory in a concrete situation. Theories are abstract and conceptual, and to this end they are never considered right or wrong. Instead, they are supported or challenged by observations in the world. They are 'rigorously tentative', meaning that they are proposed as true but expected to satisfy careful examination to account for the possibility of faulty inference or incorrect observation. Sometimes theories are falsified, meaning that an explicit set of observations contradicts some fundamental assumption of the theory, but more often theories are revised to conform to new observations, by restricting the class of phenomena the theory applies to or changing the assertions made. Sometimes a theory is set aside by scholars because there is no way to examine its assertions analytically; these may continue on in the popular imagination until some means of examination is found which either refutes or lends credence to the theory.

Philosophical theories

Theories whose subject matter consists not in empirical data, but rather in ideas are in the realm of *philosophical theories* as contrasted with *scientific theories*. At least some of the elementary theorems of a philosophical theory are statements whose truth cannot necessarily be scientifically tested through empirical observation.

Fields of study are sometimes named "theory" because their basis is some initial set of assumptions describing the field's approach to a subject matter. These assumptions are the elementary theorems of the particular theory, and can be thought of as the axioms of that field. Some commonly known examples include set theory, game theory, and number theory; however literary theory, critical theory, and music theory are also of the same form.

Metatheory

One form of philosophical theory is a *metatheory* or *meta-theory*. A metatheory is a theory whose subject matter is some other theory. In other words it is a theory about a theory. Statements made in the metatheory about the theory are called metatheorems.

Political theories

A political theory is an ethical theory about the law and government. Often the term "political theory" refers to a general view, or specific ethic, political belief or attitude, about politics.

Scientific theories

In scientific usage, the term "theory" is reserved for explanations of phenomena which meet basic requirements about the kinds of empirical observations made, the methods of classification used, and the consistency of the theory in its application among members of the class to which it pertains. These requirements vary across different scientific fields of knowledge, but in general theories are expected to be functional and parsimonious: i.e. a theory should be the simplest possible tool that can be used to effectively address the given class of phenomena. Such theories are constructed from elementary theorems that consist in empirical data about observable phenomena. A scientific theory is used as a plausible general principle or body of principles offered to explain a phenomenon.[6]

A scientific theory is a *deductive theory*, in that, its content is based on some formal system of logic and that some of its elementary theorems are taken as axioms. In a deductive theory, any sentence which is a logical consequence of one or more of the axioms is also a sentence of that theory.[5]

A major concern in construction of scientific theories is the problem of demarcation, i.e., distinguishing those ideas that are properly studied by the sciences and those that are not.

Theories are intended to be an accurate, predictive description of the natural world.

Theories as models

Theories are constructed to explain, predict, and master phenomena (e.g., inanimate things, events, or behavior of animals). A scientific theory can be thought of as a model of reality, and its statements as axioms of some axiomatic system. The aim of this construction is to create a formal system for which reality is the only model. The world is an interpretation (or model) of such scientific theories, only insofar as the sciences are true.

Theories in physics

In physics the term *theory* is generally used for a mathematical framework—derived from a small set of basic postulates (usually symmetries—like equality of locations in space or in time, or identity of electrons, etc.)—which is capable of producing experimental predictions for a given category of physical systems. A good example is classical electromagnetism, which encompasses results derived from gauge symmetry (sometimes called gauge invariance) in a form of a few equations called Maxwell's equations. Note that the specific theoretical aspects of classical electromagnetic theory, which have been consistently and successfully replicated for well over a century, are termed "laws of electromagnetism", reflecting that they are today taken for granted. Within electromagnetic theory generally, there are numerous hypotheses about how electromagnetism applies to specific situations. Many of these hypotheses are already considered to be adequately tested, with new ones always in the making and perhaps untested.

Pedagogical definition

In pedagogical contexts or in official pronouncements by official organizations of scientists a definition such as the following may be promulgated.

According to the United States National Academy of Sciences,

> Some scientific explanations are so well established that no new evidence is likely to alter them. The explanation becomes a scientific theory. In everyday language a theory means a hunch or speculation. Not so in science. In science, the word theory refers to a comprehensive explanation of an important feature of nature supported by facts gathered over time. Theories also allow scientists to make predictions about as yet unobserved phenomena, [7]

According to the American Association for the Advancement of Science,

> A scientific theory is a well-substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment. Such fact-supported theories are not "guesses" but reliable accounts of the real world. The theory of biological evolution is more than "just a theory." It is as factual an explanation of the universe as the atomic theory of matter or the germ theory of disease. Our understanding of gravity is still a work in progress. But the phenomenon of gravity, like evolution, is an accepted fact.[8]

The primary advantage enjoyed by this definition is that it firmly marks things termed theories as being well supported by evidence. This would be a disadvantage in interpreting real discourse between scientists who often use the word theory to describe untested but intricate hypotheses in addition to repeatedly confirmed models. However, in an educational or mass media setting it is almost certain that everything of the form X theory is an extremely well supported and well tested theory. This causes the theory/non-theory distinction to much more closely follow the distinctions useful for consumers of science (e.g. should I believe something or not?)

The term *theoretical*

The term *theoretical* is sometimes informally used in place of *hypothetical* to describe a result that is predicted, but has not yet been adequately tested by observation or experiment. A hypothesis is the application of a theory or theories to new conditions which has yet to be tested while a theory is a prediction based on previous observations or experiments of the same or similar circumstances. It is not, however, uncommon for a theory to produce predictions that are later confirmed or proven incorrect by experiment. By inference, a prediction proved incorrect by experiment demonstrates the hypothesis is invalid. This either means the theory is incorrect, or the experimental conjecture was wrong and the theory did not predict the hypothesis.

List of notable theories

- **Astronomy**: Big Bang Theory
- **Biology**: Cell theory — Evolution — Germ theory
- **Chemistry**: Atomic theory — Kinetic theory of gases
- **Climatology**: Climate change theory (due to anthropogenic activity)
- **Education**: Constructivist theory — Critical pedagogy theory — Education theory — Multiple intelligence theory — Progressive education theory
- **Engineering**: Circuit theory — Control theory — Signal theory — Systems theory — Information theory
- **Film**: Film Theory
- **Games**: Combinatorial game theory — Game theory — Rational choice theory
- **Geology**: Plate tectonics
- **Humanities**: Critical theory
- **Literature**: Literary theory
- **Mathematics**: Approximation theory — Arakelov theory — Asymptotic theory — Bifurcation theory — Catastrophe theory — Category theory — Chaos theory — Choquet theory — Coding theory — Deformation theory — Dimension theory — Ergodic theory — Field theory — Galois theory — Game theory — Graph theory — Group theory — Hodge theory — Homology theory — Homotopy theory — Ideal theory — Intersection theory — Invariant theory — Iwasawa theory — K-theory — KK-theory — Knot theory — L-theory — Lie theory — Littlewood–Paley theory — Matrix theory — Measure theory — Model theory — Morse theory — Nevanlinna theory — Number theory — Obstruction theory — Operator theory — PCF theory — Perturbation theory — Potential theory — Probability theory — Ramsey theory — Representation theory — Ring theory — Set theory — Shape theory — Small cancellation theory — Spectral theory — Stability theory — Stable theory — Sturm–Liouville theory — Twistor theory
- **Music**: Music theory
- **Philosophy**: Proof theory — Speculative reason — Theory of truth — Type theory — Value theory — Virtue theory
- **Physics**: Acoustic theory — Antenna theory — BCS theory — Landau theory — M-theory — Perturbation theory — Theory of relativity — Quantum field theory — Scattering theory — String theory
- **Planetary science**: Giant impact theory
- **Visual Art**: Aesthetics — Art Educational theory — Architecture — Composition — Anatomy — Color theory — Perspective — Visual perception — Geometry — Manifolds
- **Sociology**: Sociological theory — Social theory — Critical theory
- **Sports**: Chess theory
- **Statistics** : Extreme value theory
- **Theatre** : Theory relating to theatrical performance.
- **Other**: Obsolete scientific theories — Phlogiston theory

See also

- Falsifiability
- Formal language
- Formal system
- Hypothesis
- Hypothesis testing
- Model
- Predictive power
- Scientific method
- Testability

Notes

[1] Originally the word "theory" was used in Greek philosophy; for example, that of Plato. It is related to θεωρός "spectator", θέα *thea* "a view" + ὁρᾶν *horan* "to see", literally "looking at a show". See for example dictionary entries at Perseus website (http://www.perseus.tufts.edu/hopper/resolveform?type=start&lookup=qewr&lang=greek). The word has been in use in English since at least the late 16th century.Harper, Douglas. "theory" (http://www.etymonline.com/index.php?term=theory). *Online Etymology Dictionary*. . Retrieved 2008-07-18.

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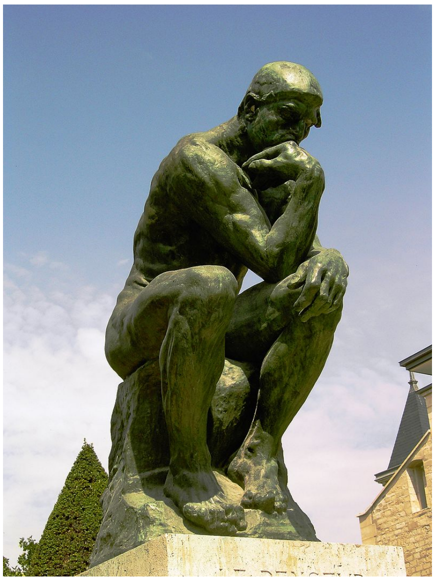
Thought

Thoughts are forms conceived in the mind, rather than the forms perceived through the five senses. **Thought** and **thinking** are the processes by which these concepts are perceived and manipulated. Thinking allows beings to model the world and to represent it according to their objectives, plans, ends and desires. Similar concepts and processes include cognition, sentience, consciousness, ideas, and imagination.[1]


Statue "The Thinker" depicting a person thinking.

Definition

Representative reactions towards stimuli from internal chemical reactions or external environmental factors (this definition precludes the notion that anything inorganic could ever be made to "think": An idea contested by such computer scientists as Alan Turing (see Computing Machinery and Intelligence)). The word comes from Old English þoht, geþoht, from stem of þencan "to conceive of in the mind, consider".[2]

In common language, the word *thinking* covers numerous diverse psychological activities. It is sometimes a synonym for "tending to believe," especially with less than full confidence ("I think that it will rain, but I am not sure"). At other times it denotes the degree of attentiveness ("I did it without thinking") or whatever is in consciousness, especially if it refers to something outside the immediate environment ("It made me think of my grandmother").

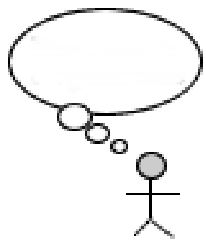


Illustration depicting thought.

Philosophy

Philosophy of mind is a branch of modern analytic philosophy that studies the nature of the mind, mental events, mental functions, mental properties, consciousness and their relationship to the physical body, particularly the brain. The mind-body problem, i.e. the relationship of the mind to the body, is commonly seen as the central issue in philosophy of mind, although there are other issues concerning the nature of the mind that do not involve its relation to the physical body.[3]

The mind-body problem

The mind-body problem concerns the explanation of the relationship that exists between minds, or mental processes, and bodily states or processes.[3] The main aim of philosophers working in this area is to determine the nature of the mind and mental states/processes, and how—or even if—minds are affected by and can affect the body.

Human perceptual experiences depend on stimuli which arrive at one's various sensory organs from the external world and these stimuli cause changes in one's mental state, ultimately causing one to feel a sensation, which may be pleasant or unpleasant. Someone's desire for a slice of pizza, for example, will tend to cause that person to move his or her body in a specific manner and in a specific direction to obtain what he or she wants. The question, then, is how it can be possible for conscious experiences to arise out of a lump of gray matter endowed with nothing but electrochemical properties. A related problem is to explain how someone's propositional attitudes (e.g. beliefs and desires) can cause that individual's neurons to fire and his muscles to contract in exactly the correct manner. These comprise some of the puzzles that have confronted epistemologists and philosophers of mind from at least the time of René Descartes.[4]

Biology

A neuron (also known as a neurone or nerve cell) is an excitable cell in the nervous system that processes and transmits information by electrochemical signalling. Neurons are the core components of the brain, the vertebrate spinal cord, the invertebrate ventral nerve cord, and the peripheral nerves. A number of specialized types of neurons exist: sensory neurons respond to touch, sound, light and numerous other stimuli affecting cells of the sensory organs that then send signals to the spinal cord and brain. Motor neurons receive signals from the brain and spinal cord and cause muscle contractions and affect glands. Interneurons connect neurons to other neurons within the brain and spinal cord. Neurons respond to stimuli, and communicate the presence of stimuli to the central nervous system, which processes that information and sends responses to other parts of the body for action. Neurons do not go through mitosis, and usually cannot be replaced after being destroyed, although astrocytes have been observed to turn into neurons as they are sometimes pluripotent.

Psychology

Psychologists have concentrated on thinking as an intellectual exertion aimed at finding an answer to a question or the solution of a practical problem. Cognitive psychology is a branch of psychology that investigates internal mental processes such as problem solving, memory, and language. The school of thought arising from this approach is known as cognitivism which is interested in how people mentally represent information processing. It had its foundations in the Gestalt psychology of Max Wertheimer, Wolfgang Köhler, and Kurt Koffka,[5] and in the work of Jean Piaget, who provided a theory of stages/phases that describe children's cognitive development.

Cognitive psychologists use psychophysical and experimental approaches to understand, diagnose, and solve problems, concerning themselves with the mental processes which mediate between stimulus and response. They study various aspects of thinking, including the psychology of reasoning, and how people make decisions and choices, solve problems, as well as engage in creative discovery and imaginative thought. Cognitive theory contends that solutions to problems take the form of algorithms—rules that are not necessarily understood but promise a solution, or heuristics—rules that are understood but that do not always guarantee solutions. Cognitive science differs from cognitive psychology in that algorithms that are intended to simulate human behavior are implemented or implementable on a computer. In other instances, solutions may be found through insight, a sudden awareness of relationships.

In developmental psychology, Jean Piaget was a pioneer in the study of the development of thought from birth to maturity. In his theory of cognitive development, thought is based on actions on the environment. That is, Piaget suggests that the environment is understood through assimilations of objects in the available schemes of action and these accommodate to the objects to the extent that the available schemes fall short of the demands. As a result of this interplay between assimilation and accommodation, thought develops through a sequence of stages that differ qualititatively from each other in mode of representation and complexity of inference and understanding. That is, thought evolves from being based on perceptions and actions at the sensorimotor stage in the first two years of life to internal representations in early childhood. Subsequently, representations are gradually organized into logical structures which first operate on the concrete properties of the reality, in the stage of concrete operations, and then operate on abstract principles that organize concrete properties, in the stage of formal operations.[6] In recent years, the Piagetian conception of thought was integrated with information processing conceptions. Thus, thought is considered as the result of information processing mechanisms that are responsible for the representation and processing of information. In this conception, speed of processing, cognitive control, and working memory are the main functions underlying thought. In the neo-Piagetian theories of cognitive development, the development of thought is considered to come from increasing speed of processing, enhanced cognitive control, and increasing working memory.[7]

Psychoanalysis

"Id", "ego", and "super-ego" are the three parts of the "psychic apparatus" defined in Sigmund Freud's structural model of the psyche; they are the three theoretical constructs in terms of whose activity and interaction mental life is described. According to this model, the uncoordinated instinctual trends are the "id"; the organized realistic part of the psyche is the "ego," and the critical and moralizing function the "super-ego."[8]

The unconscious was considered by Freud throughout the evolution of his psychoanalytic theory a sentient force of will influenced by human desire and yet operating well below the perceptual conscious mind. For Freud, the unconscious is the storehouse of instinctual desires, needs, and psychic drives. While past thoughts and reminiscences may be concealed from immediate consciousness, they direct the thoughts and feelings of the individual from the realm of the unconscious.[9]

For psychoanalysis, the unconscious does not include all that is not conscious, rather only what is actively repressed from conscious thought or what the person is averse to knowing consciously. In a sense this view places the self in relationship to their unconscious as an adversary, warring with itself to keep what is unconscious hidden. If a person feels pain, all he can think of is alleviating the pain. Any of his desires, to get rid of pain or enjoy something, command the mind what to do. For Freud, the unconscious was a repository for socially unacceptable ideas, wishes or desires, traumatic memories, and painful emotions put out of mind by the mechanism of psychological repression. However, the contents did not necessarily have to be solely negative. In the psychoanalytic view, the unconscious is a force that can only be recognized by its effects—it expresses itself in the symptom.[10]

Sociology

Social psychology is the study of how people and groups interact. Scholars in this interdisciplinary area are typically either psychologists or sociologists, though all social psychologists employ both the individual and the group as their units of analysis.[11]

Despite their similarity, psychological and sociological researchers tend to differ in their goals, approaches, methods, and terminology. They also favor separate academic journals and professional societies. The greatest period of collaboration between sociologists and psychologists was during the years immediately following World War II.[12] Although there has been increasing isolation and specialization in recent years, some degree of overlap and influence remains between the two disciplines.[13]

The collective unconscious, sometimes known as collective subconscious, is a term of analytical psychology, coined by Carl Jung. It is a part of the unconscious mind, shared by a society, a people, or all humanity, in an interconnected system that is the product of all common experiences and contains such concepts as science, religion, and morality. While Freud did not distinguish between an "individual psychology" and a "collective psychology," Jung distinguished the collective unconscious from the personal subconscious particular to each human being. The collective unconscious is also known as "a reservoir of the experiences of our species."[14]

In the "Definitions" chapter of Jung's seminal work *Psychological Types*, under the definition of "collective" Jung references *representations collectives*, a term coined by Lucien Lévy-Bruhl in his 1910 book *How Natives Think*. Jung says this is what he describes as the collective unconscious. Freud, on the other hand, did not accept the idea of a collective unconscious.

See also

- Critical thinking
- Reasoning

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Truth

Time Saving Truth from Falsehood and Envy, François Lemoyne, 1737

Truth can have a variety of meanings, such as the state of being in accord with a particular fact or reality, or being in accord with the body of real things, real events or actualities.[1] It can also mean having fidelity to an original or to a standard or ideal. In a common archaic usage it also meant constancy or sincerity in action or character.[1] The direct opposite of truth is "falsehood", which can correspondingly take logical, factual or ethical meanings.

Various theories and views of truth continue to be debated among scholars and philosophers. There are differing claims on such questions as what constitutes truth; what things are truthbearers capable of being true or false; how to define and identify truth; the roles that revealed and acquired knowledge play; and whether truth is subjective, relative, objective, or absolute. This article introduces the various perspectives and claims, both today and throughout history.

Nomenclature, orthography and etymology

The English word *truth* is from Old English *tríewþ, tréowþ, trýwþ*, Middle English *trewþe*, cognate to Old High German *triuwida*, Old Norse *tryggð*. Like *troth*, it is a *-th* nominalisation of the adjective *true* (Old English *tréowe*).

The English word *true* is from Old English (West Saxon) *(ge)tríewe, tréowe*, cognate to Old Saxon *(gi)trûui*, Old High German *(ga)triuwu* (Modern German *treu* "faithful"), Old Norse *tryggr*, Gothic *triggws*,[2] all from a Proto-Germanic **trewwj-* "having good faith". Old Norse *trú*, "faith, word of honour; religious faith, belief"[3] (archaic English *troth* "loyalty, honesty, good faith", compare *Ásatrú*).

Thus, 'truth' involves both the quality of "faithfulness, fidelity, loyalty, sincerity, veracity",[4] and that of "agreement with fact or reality", in Anglo-Saxon expressed by *sōþ* (Modern English *sooth*).

All Germanic languages besides English have introduced a terminological distinction between truth "fidelity" and truth "factuality". To express "factuality", North Germanic opted for nouns derived from *sanna* "to assert, affirm", while continental West Germanic (German and Dutch) opted for continuations of *wâra* "faith, trust, pact" (cognate to Slavic *věra* "(religious) faith", but influenced by Latin *verus*). Romance languages use terms following the Latin *veritas*, while the Greek *aletheia* and Slavic *pravda* have separate etymological origins.

The major theories of truth

The question of what is a proper basis for deciding how words, symbols, ideas and beliefs may properly be considered true, whether by a single person or an entire society, is dealt with by the five major substantive theories introduced below. Each theory presents perspectives that are widely shared by published scholars.[5] [6] There also have more recently arisen "deflationary" or "minimalist" theories of truth based on the idea that the application of a term like *true* to a statement does not assert anything significant about it, for instance, anything about its *nature*, but that the label *truth* is a tool of discourse used to express agreement, to emphasize claims, or to form certain types of generalizations.[5] [7] [8]

Substantive theories

Correspondence theory

Truth, holding a mirror and a serpent (1896). Olin Levi Warner, Library of Congress Thomas Jefferson Building, Washington, D.C.

Correspondence theories state that true beliefs and true statements correspond to the actual state of affairs.[9] This type of theory posits a relationship between thoughts or statements on the one hand, and things or objects on the other. It is a traditional model which goes back at least to some of the classical Greek philosophers such as Socrates, Plato, and Aristotle.[10] This class of theories holds that the truth or the falsity of a representation is determined in principle solely by how it relates to "things", by whether it accurately describes those "things". An example of correspondence theory is the statement by the Thirteenth Century philosopher/theologian Thomas Aquinas: *Veritas est adaequatio rei et intellectus* ("Truth is the equation [or adequation] of things and intellect"), a statement which Aquinas attributed to the Ninth Century neoplatonist Isaac Israeli.[11] [12] Aquinas also restated the theory as: “A judgment is said to be true when it conforms to the external reality” [13]

Correspondence theory practically operates on the assumption that truth is a matter of accurately copying what was much later called "objective reality" and then representing it in thoughts, words and other symbols.[14] Many modern theorists have stated that this ideal cannot be achieved independently of some analysis of additional factors.[5] [15] For example, language plays a role in that all languages have words that are not easily translatable into another. The German word *Zeitgeist* is one such example: one who speaks or understands the language may "know" what it means, but any translation of the word fails to accurately capture its full meaning (this is a problem with many abstract words, especially those derived in agglutinative languages). Thus, some words add an additional parameter to the construction of an accurate truth predicate. Among the philosophers who grappled with this problem is Alfred Tarski, whose semantic theory is summarized further below in this article.[16]

Proponents of several of the theories below have gone further to assert that there are yet other issues necessary to the analysis, such as interpersonal power struggles, community interactions, personal biases and other factors involved in deciding what is seen as truth.

Coherence theory

For coherence theories in general, truth requires a proper fit of elements within a whole system. Very often, though, coherence is taken to imply something more than simple logical consistency; often there is a demand that the propositions in a coherent system lend mutual inferential support to each other. So, for example, the completeness and comprehensiveness of the underlying set of concepts is a critical factor in judging the validity and usefulness of a coherent system.[17] A pervasive tenet of coherence theories is the idea that truth is primarily a property of whole systems of propositions, and can be ascribed to individual propositions only according to their coherence with the whole. Among the assortment of perspectives commonly regarded as coherence theory, theorists differ on the question of whether coherence entails many possible true systems of thought or only a single absolute system.

Some variants of coherence theory are claimed to characterize the essential and intrinsic properties of formal systems in logic and mathematics.[18] However, formal reasoners are content to contemplate axiomatically independent and sometimes mutually contradictory systems side by side, for example, the various alternative geometries. On the whole, coherence theories have been criticized as lacking justification in their application to other areas of truth, especially with respect to assertions about the natural world, empirical data in general, assertions about practical matters of psychology and society, especially when used without support from the other major theories of truth.[19]

Coherence theories distinguish the thought of rationalist philosophers, particularly of Spinoza, Leibniz, and G.W.F. Hegel, along with the British philosopher F.H. Bradley.[20] They have found a resurgence also among several proponents of logical positivism, notably Otto Neurath and Carl Hempel.

Constructivist theory

Social constructivism holds that truth is constructed by social processes, is historically and culturally specific, and that it is in part shaped through the power struggles within a community. Constructivism views all of our knowledge as "constructed," because it does not reflect any external "transcendent" realities (as a pure correspondence theory might hold). Rather, perceptions of truth are viewed as contingent on convention, human perception, and social experience. It is believed by constructivists that representations of physical and biological reality, including race, sexuality, and gender are socially constructed.

Giambattista Vico was among the first to claim that history and culture were man-made. Vico's epistemological orientation gathers the most diverse rays and unfolds in one axiom – *verum ipsum factum* – "truth itself is constructed". Hegel and Marx were among the other early proponents of the premise that truth is, or can be, socially constructed. Marx, like many critical theorists who followed, did not reject the existence of objective truth but rather distinguished between true knowledge and knowledge that has been distorted through power or ideology. For Marx scientific and true knowledge is 'in accordance with the dialectical understanding of history' and ideological knowledge 'an epiphenomenal expression of the relation of material forces in a given economic arrangement'.[21]

Consensus theory

Consensus theory holds that truth is whatever is agreed upon, or in some versions, might come to be agreed upon, by some specified group. Such a group might include all human beings, or a subset thereof consisting of more than one person.

Among the current advocates of consensus theory as a useful accounting of the concept of "truth" is the philosopher Jürgen Habermas.[22] Habermas maintains that truth is what would be agreed upon in an ideal speech situation.[23] Among the current strong critics of consensus theory is the philosopher Nicholas Rescher.[24]

Pragmatic theory

The three most influential forms of the *pragmatic theory of truth* were introduced around the turn of the 20th century by Charles Sanders Peirce, William James, and John Dewey. Although there are wide differences in viewpoint among these and other proponents of pragmatic theory, they hold in common that truth is verified and confirmed by the results of putting one's concepts into practice.[25]

Peirce defines truth as follows: "Truth is that concordance of an abstract statement with the ideal limit towards which endless investigation would tend to bring scientific belief, which concordance the abstract statement may possess by virtue of the confession of its inaccuracy and one-sidedness, and this confession is an essential ingredient of truth."[26] This statement emphasizes Peirce's view that ideas of approximation, incompleteness, and partiality, what he describes elsewhere as *fallibilism* and "reference to the future", are essential to a proper conception of truth. Although Peirce uses words like *concordance* and *correspondence* to describe one aspect of the pragmatic sign relation, he is also quite explicit in saying that definitions of truth based on mere correspondence are no more than *nominal* definitions, which he accords a lower status than *real* definitions.

William James's version of pragmatic theory, while complex, is often summarized by his statement that "the 'true' is only the expedient in our way of thinking, just as the 'right' is only the expedient in our way of behaving."[27] By this, James meant that truth is a quality the value of which is confirmed by its effectiveness when applying concepts to actual practice (thus, "pragmatic").

John Dewey, less broadly than James but more broadly than Peirce, held that inquiry, whether scientific, technical, sociological, philosophical or cultural, is self-corrective over time *if* openly submitted for testing by a community of inquirers in order to clarify, justify, refine and/or refute proposed truths.[28]

Minimalist (deflationary) theories

A number of philosophers reject the thesis that the concept or term *truth* refers to a real property of sentences or propositions. These philosophers are responding, in part, to the common use of *truth predicates* (e.g., that some particular thing "...is true") which was particularly prevalent in philosophical discourse on truth in the first half of the 20th century. From this point of view, to assert the proposition “'2 + 2 = 4' is true” is logically equivalent to asserting the proposition “2 + 2 = 4”, and the phrase “is true” is completely dispensable in this and every other context. These positions are broadly described

- as *deflationary* theories of truth, since they attempt to deflate the presumed importance of the words "true" or *truth*,
- as *disquotational* theories, to draw attention to the disappearance of the quotation marks in cases like the above example, or
- as *minimalist* theories of truth.[5] [29]

Whichever term is used, deflationary theories can be said to hold in common that "[t]he predicate 'true' is an expressive convenience, not the name of a property requiring deep analysis."[5] Once we have identified the truth predicate's formal features and utility, deflationists argue, we have said all there is to be said about truth. Among the theoretical concerns of these views is to explain away those special cases where it *does* appear that the concept of truth has peculiar and interesting properties. (See, e.g., Semantic paradoxes, and below.)

In addition to highlighting such formal aspects of the predicate "is true", some deflationists point out that the concept enables us to express things that might otherwise require infinitely long sentences. For example, one cannot express confidence in Michael's accuracy by asserting the endless sentence:

> *Michael says, 'snow is white' and snow is white, or he says 'roses are red' and roses are red or he says ... etc.*

This assertion can also be succinctly expressed by saying: *What Michael says is true*.[30]

Performative theory of truth

Attributed to P. F. Strawson is the performative theory of truth which holds that to say "'Snow is white' is true" is to perform the speech act of signaling one's agreement with the claim that snow is white (much like nodding one's head in agreement). The idea that some statements are more actions than communicative statements is not as odd as it may seem. Consider, for example, that when the bride says "I do" at the appropriate time in a wedding, she is performing the act of taking this man to be her lawful wedded husband. She is not *describing* herself as taking this man, but actually doing so (perhaps the most thorough analysis of such "illocutionary acts" is J. L. Austin, "How to Do Things With Words"[31]).

Strawson holds that a similar analysis is applicable to all speech acts, not only to illocutionary ones: "To say a statement is true is not to make a statement about a statement, but rather to perform the act of agreeing with, accepting, or endorsing a statement. When one says 'It's true that it's raining,' one asserts no more than 'It's raining.' The function of [the statement] 'It's true that...' is to agree with, accept, or endorse the statement that 'it's raining.'"[32]

Redundancy and related theories

According to the redundancy theory of truth, asserting that a statement is true is completely equivalent to asserting the statement itself. For example, making the assertion that " 'Snow is white' is true" is equivalent to asserting "Snow is white". Redundancy theorists infer from this premise that truth is a redundant concept; that is, it is merely a word that is traditionally used in conversation or writing, generally for emphasis, but not a word that actually equates to anything in reality. This theory is commonly attributed to Frank P. Ramsey, who held that the use of words like *fact* and *truth* was nothing but a roundabout way of asserting a proposition, and that treating these words as separate problems in isolation from judgment was merely a "linguistic muddle".[5] [33] [34]

A variant of redundancy theory is the disquotational theory which uses a modified form of Tarski's schema: To say that '"P" is true' is to say that P. Yet another version of deflationism is the prosentential theory of truth, first developed by Dorothy Grover, Joseph Camp, and Nuel Belnap as an elaboration of Ramsey's claims. They argue that sentences like "That's true", when said in response to "It's raining", are prosentences, expressions that merely repeat the content of other expressions. In the same way that *it* means the same as *my dog* in the sentence *My dog was hungry, so I fed it*, *That's true* is supposed to mean the same as *It's raining* — if you say the latter and I then say the former. These variations do not necessarily follow Ramsey in asserting that truth is *not* a property, but rather can be understood to say that, for instance, the assertion "P" may well involve a substantial truth, and the theorists in this case are minimalizing only the redundancy or prosentence involved in the statement such as "that's true."[5]

Deflationary principles do not apply to representations that are not analogous to sentences, and also do not apply to many other things that are commonly judged to be true or otherwise. Consider the analogy between the sentence "Snow is white" and the character named Snow White, both of which can be true in some sense. To a minimalist, saying "Snow is white is true" is the same as saying "Snow is white," but to say "Snow White is true" is *not* the same as saying "Snow White."

Pluralist theories

Several of the major theories of truth hold that there is a particular property the having of which makes a belief or proposition true. Pluralist theories of truth assert that there may be more than one property that makes propositions true: ethical propositions might be true by virtue of coherence. Propositions about the physical world might be true by corresponding to the objects and properties they are about.

Some of the pragmatic theories, such as those by Charles Peirce and William James, included aspects of correspondence, coherence and constructivist theories.[26] [27] Crispin Wright argued in his 1992 book *Truth and Objectivity* that any predicate which satisfied certain platitudes about truth qualified as a truth predicate. In some discourses, Wright argued, the role of the truth predicate might be played by the notion of superassertibility.[35] Michael Lynch, in a 2009 book *Truth as One and Many*, argued that we should see truth as a functional property capable of being multiply manifested in distinct properties like correspondence or coherence.[36]

Most believed theories

According to a survey of professional philosophers and others on their philosophical views which was carried out in November 2009 (taken by 3226 respondents, including 1803 philosophy faculty members and/or PhDs and 829 philosophy graduate students) 44.9% of respondents accept or lean towards correspondence theories, 20.7% accept or lean towards deflationary theories and 13.8% epistemic theories.[37]

Formal theories

Truth in logic

Logic is concerned with the patterns in reason that can help tell us if a proposition is true or not. However, logic does not deal with truth in the absolute sense, as for instance a metaphysician does. Logicians use formal languages to express the truths which they are concerned with, and as such there is only truth under some interpretation or truth within some logical system.

A logical truth (also called an analytic truth or a necessary truth) is a statement which is true in all possible worlds[38] or under all possible interpretations, as contrasted to a *fact* (also called a *synthetic claim* or a *contingency*) which is only true in this world as it has historically unfolded. A proposition such as “If p and q, then p.” is considered to be logical truth because it is true because of the meaning of the symbols and words in it and not because of any facts of any particular world. They are such that they could not be untrue.

Truth in mathematics

There are two main approaches to truth in mathematics. They are the *model theory of truth* and the *proof theory of truth*.

Historically, with the nineteenth century development of Boolean algebra mathematical models of logic began to treat "truth", also represented as "T" or "1", as an arbitrary constant. "Falsity" is also an arbitrary constant, which can be represented as "F" or "0". In propositional logic, these symbols can be manipulated according to a set of axioms and rules of inference, often given in the form of truth tables.

In addition, from at least the time of Hilbert's program at the turn of the twentieth century to the proof of Gödel's theorem and the development of the Church-Turing thesis in the early part of that century, true statements in mathematics were generally assumed to be those statements which are provable in a formal axiomatic system.

The works of Kurt Gödel, Alan Turing, and others shook this assumption, with the development of statements that are true but cannot be proven within the system.[39] Two examples of the latter can be found in Hilbert's problems. Work on Hilbert's 10th problem led in the late twentieth century to the construction of specific Diophantine equations for which it is undecidable whether they have a solution,[40] or even if they do, whether they have a finite or infinite number of solutions. More fundamentally, Hilbert's first problem was on the continuum hypothesis.[41] Gödel and Paul Cohen showed that this hypothesis cannot be proved or disproved using the standard axioms of set theory and a finite number of proof steps.[42] In the view of some, then, it is equally reasonable to take either the continuum hypothesis or its negation as a new axiom.

Semantic theory of truth

The semantic theory of truth has as its general case for a given language:

> 'P' is true if and only if P

where 'P' is a reference to the sentence (the sentence's name), and P is just the sentence itself.

Logician and philosopher Alfred Tarski developed the theory for formal languages (such as formal logic). Here he restricted it in this way: no language could contain its own truth predicate, that is, the expression *is true* could only apply to sentences in some other language. The latter he called an *object language*, the language being talked about. (It may, in turn, have a truth predicate that can be applied to sentences in still another language.) The reason for his restriction was that languages that contain their own truth predicate will contain paradoxical sentences like the Liar: *This sentence is not true*. See The Liar paradox. As a result Tarski held that the semantic theory could not be applied to any natural language, such as English, because they contain their own truth predicates. Donald Davidson used it as the foundation of his truth-conditional semantics and linked it to radical interpretation in a form of coherentism.

Bertrand Russell is credited with noticing the existence of such paradoxes even in the best symbolic formalizations of mathematics in his day, in particular the paradox that came to be named after him, Russell's paradox. Russell and Whitehead attempted to solve these problems in *Principia Mathematica* by putting statements into a hierarchy of types, wherein a statement cannot refer to itself, but only to statements lower in the hierarchy. This in turn led to new orders of difficulty regarding the precise natures of types and the structures of conceptually possible type systems that have yet to be resolved to this day.

Kripke's theory of truth

Saul Kripke contends that a natural language can in fact contain its own truth predicate without giving rise to contradiction. He showed how to construct one as follows:

- Begin with a subset of sentences of a natural language that contains no occurrences of the expression "is true" (or "is false"). So *The barn is big* is included in the subset, but not " *The barn is big* is true", nor problematic sentences such as "*This sentence* is false".
- Define truth just for the sentences in that subset.
- Then extend the definition of truth to include sentences that predicate truth or falsity of one of the original subset of sentences. So "*The barn is big* is true" is now included, but not either "*This sentence* is false" nor "'*The barn is big* is true' is true".
- Next, define truth for all sentences that predicate truth or falsity of a member of the second set. Imagine this process repeated infinitely, so that truth is defined for *The barn is big*; then for "*The barn is big* is true"; then for "'*The barn is big* is true' is true", and so on.

Notice that truth never gets defined for sentences like *This sentence is false*, since it was not in the original subset and does not predicate truth of any sentence in the original or any subsequent set. In Kripke's terms, these are "ungrounded." Since these sentences are never assigned either truth or falsehood even if the process is carried out infinitely, Kripke's theory implies that some sentences are neither true nor false. This contradicts the Principle of bivalence: every sentence must be either true or false. Since this principle is a key premise in deriving the Liar paradox, the paradox is dissolved.[43]

Notable views

Ancient history

La Vérité ("Truth") by Jules Joseph Lefebvre

The ancient Greek origins of the words "true" and "truth" have some consistent definitions throughout great spans of history that were often associated with topics of logic, geometry, mathematics, deduction, induction, and natural philosophy.

Socrates', Plato's and Aristotle's ideas about truth are commonly seen as consistent with correspondence theory. In his *Metaphysics*, Aristotle stated: “To say of what is that it is not, or of what is not that it is, is false, while to say of what is that it is, and of what is not that it is not, is true”.[44] The Stanford Encyclopedia of Philosophy proceeds to say of Aristotle:

> Aristotle sounds much more like a genuine correspondence theorist in the *Categories* (12b11, 14b14), where he talks of “underlying things” that make statements true and implies that these “things” (pragmata) are logically structured situations or facts (viz., his sitting, his not sitting). Most influential is his claim in *De Interpretatione* (16a3) that thoughts are “likenessess” (homoiosis) of things. Although he nowhere defines truth in terms of a thought's likeness to a thing or fact, it is clear that such a definition would fit well into his overall philosophy of mind.[44]

Very similar statements can also be found in Plato (Cratylus 385b2, Sophist 263b).[44]

Medieval age

Avicenna

In early Islamic philosophy, Avicenna (Ibn Sina) defined truth in his Metaphysics of Healing, Book I, Chapter 8, as:

> What corresponds in the mind to what is outside it.[45]

Avicenna elaborated on his definition of truth in his *Metaphysics* Book Eight, Chapter 6:

> The truth of a thing is the property of the being of each thing which has been established in it.[46]

However, this definition is merely a translation of the Latin translation from the Middle Ages.[47] A modern translation of the original Arabic text states:

> Truth is also said of the veridical belief in the existence [of something].[48]

Aquinas

Following Avicenna, and also Augustine and Aristotle, Thomas Aquinas stated in his *Disputed Questions on Truth*:

> A natural thing, being placed between two intellects, is called *true* insofar as it conforms to either. It is said to be true with respect to its conformity with the divine intellect insofar as it fulfills the end to which it was ordained by the divine intellect... With respect to its conformity with a human intellect, a thing is said to be true insofar as it is such as to cause a true estimate about itself.[49]

Thus, for Aquinas, the truth of the human intellect (logical truth) is based on the truth in things (ontological truth).[50] Following this, he wrote an elegant re-statement of Aristotle's view in his Summa I.16.1 [51]:

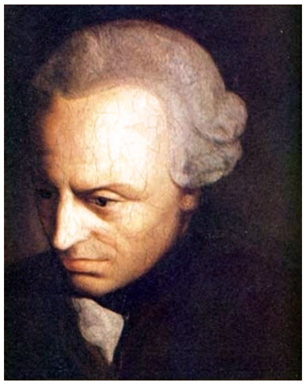
> Veritas est adæquatio intellectus et rei.
> (Truth is the conformity of the intellect to the things.)

Aquinas also said that real things participate in the act of being of the Creator God who is Subsistent Being, Intelligence, and Truth. Thus, these beings possess the light of intelligibility and are knowable. These things (beings; reality) are the foundation of the truth that is found in the human mind, when it acquires knowledge of things, first through the senses, then through the understanding and the judgement done by reason. For Aquinas, human intelligence ("intus", within and "legere", to read) has the capability to reach the essence and existence of things because it has a non-material, spiritual element, although some moral, educational, and other elements might interfere with its capability.

Modern age

Kant

Immanuel Kant discussed the correspondence theory of truth[44] in the following manner, criticizing correspondence theory as circular reasoning.



Immanuel Kant

> Truth is said to consist in the agreement of knowledge with the object. According to this mere verbal definition, then, my knowledge, in order to be true, must agree with the object. Now, I can only compare the object with my knowledge by this means, namely, by taking knowledge of it. My knowledge, then, is to be verified by itself, which is far from being sufficient for truth. For as the object is external to me, and the knowledge is in me, I can only judge whether my knowledge of the object agrees with my knowledge of the object. Such a circle in explanation was called by the ancients Diallelos. And the logicians

> were accused of this fallacy by the sceptics, who remarked that this account of truth was as if a man before a judicial tribunal should make a statement, and appeal in support of it to a witness whom no one knows, but who defends his own credibility by saying that the man who had called him as a witness is an honourable man.[52]

According to Kant, the definition of truth as correspondence is a "mere verbal definition", here making use of Aristotle's distinction between a nominal definition: a definition in name only, and a real definition: a definition that shows the true cause or essence of the term that is being defined. From Kant's account of the history, the definition of truth as correspondence was already in dispute from classical times, the "skeptics" criticizing the "logicians" for a form of circular reasoning, though the extent to which the "logicians" actually held such a theory is not evaluated.[52]

Hegel

Hegel tried to distance his philosophy from psychology by presenting truth as being an external self–moving object instead of being related to inner, subjective thoughts. Hegel's truth is analogous to the mechanics of a material body in motion under the influence of its own inner force. "Truth is its own self–movement within itself."[53] Teleological truth moves itself in the three–step form of dialectical triplicity toward the final goal of perfect, final, absolute truth. For Hegel, the progression of philosophical truth is a resolution of past oppositions into increasingly more accurate approximations to absolute truth. Chalybäus used the terms "thesis", "antithesis", and "synthesis" to describe Hegel's dialectical triplicity. The "thesis" consists of an incomplete historical movement. To resolve the incompletion, an "antithesis" occurs which opposes the "thesis." In turn, the "synthesis" appears when the "thesis" and "antithesis" become reconciled and a higher level of truth is obtained. This "synthesis" thereby becomes a "thesis," which will again necessitate an "antithesis," requiring a new "synthesis" until a final state is reached as the result of reason's historical movement. History is the Absolute Spirit moving toward a goal. This historical progression will finally conclude itself when the Absolute Spirit understands its own infinite self at the very end of history. Absolute Spirit will then be the complete expression of an infinite God.

Schopenhauer

For Schopenhauer,[54] a judgment is a combination or separation of two or more concepts. If a judgment is to be an expression of knowledge, it must have a sufficient reason or ground by which the judgment could be called true. *Truth is the reference of a judgment to something different from itself which is its sufficient reason (ground).* Judgments can have material, formal, transcendental, or metalogical truth. A judgment has *material* truth if its concepts are based on intuitive perceptions that are generated from sensations. If a judgment has its reason (ground) in another judgment, its truth is called logical or *formal*. If a judgment, of, for example, pure mathematics or pure science, is based on the forms (space, time, causality) of intuitive, empirical knowledge, then the judgment has *transcendental* truth.

Kierkegaard

When Søren Kierkegaard, as his character *Johannes Climacus*, wrote that *"Truth is Subjectivity"*, he does not advocate for subjectivism in its extreme form (the theory that something is true simply because one believes it to be so), but rather that the objective approach to matters of personal truth cannot shed any light upon that which is most essential to a person's life. Objective truths are concerned with the facts of a person's being, while subjective truths are concerned with a person's way of being. Kierkegaard agrees that objective truths for the study of subjects like mathematics, science, and history are relevant and necessary, but argues that objective truths do not shed any light on a person's inner relationship to existence. At best, these truths can only provide a severely narrowed perspective that has little to do with one's actual experience of life.[55]

While objective truths are final and static, subjective truths are continuing and dynamic. The truth of one's existence is a living, inward, and subjective experience that is always in the process of becoming. The values, morals, and spiritual approaches a person adopts, while not denying the existence of objective truths of those beliefs, can only become truly known when they have been inwardly appropriated through subjective experience. Thus, Kierkegaard criticizes all systematic philosophies which attempt to know life or the truth of existence via theories and objective knowledge about reality. As Kierkegaard claims, human truth is something that is continually occurring, and a human being cannot find truth separate from the subjective experience of one's own existing, defined by the values and fundamental essence that consist of one's way of life.[56]

Nietzsche

Friedrich Nietzsche believed the search for truth or 'the will to truth' was a consequence of the *will to power* of philosophers. He thought that truth should be used as long as it promoted life and the will to power, and he thought untruth was better than truth if it had this life enhancement as a consequence. As he wrote in *Beyond Good and Evil*, "*The falseness of a judgment is to us not necessarily an objection to a judgment... The question is to what extent it is life-advancing, life-preserving, species-preserving, perhaps even species-breeding...*" (aphorism 4). He proposed the *will to power* as a truth only because according to him it was the most life affirming and sincere perspective one could have.

Robert Wicks discusses Nietzsche's basic view of truth as follows:

> Some scholars regard Nietzsche's 1873 unpublished essay, "On Truth and Lies in a Nonmoral Sense" ("Über Wahrheit und Lüge im außermoralischen Sinn") as a keystone in his thought. In this essay, Nietzsche rejects the idea of universal constants, and claims that what we call "truth" is only "a mobile army of metaphors, metonyms, and anthropomorphisms." His view at this time is that arbitrariness completely prevails within human experience: concepts originate via the very artistic transference of nerve stimuli into images; "truth" is nothing more than the invention of fixed conventions for merely practical purposes, especially those of repose, security and consistence.[57]

Whitehead

Alfred North Whitehead a British mathematician who became an American philosopher, said: "There are no whole truths; all truths are half-truths. It is trying to treat them as whole truths that play the devil".

The logical progression or connection of this line of thought is to conclude that truth can lie, since half-truths are deceptive and may lead to a false conclusion.

Nishida

According to Kitaro Nishida, "knowledge of things in the world begins with the differentiation of unitary consciousness into knower and known and ends with self and things becoming one again. Such unification takes form not only in knowing but in the valuing (of truth) that directs knowing, the willing that directs action, and the feeling or emotive reach that directs sensing."[58]

Fromm

Erich Fromm finds that trying to discuss truth as "absolute truth" is sterile and that emphasis ought to be placed on "optimal truth". He considers truth as stemming from the survival imperative of grasping one's environment physically and intellectually, whereby young children instinctively seek truth so as to orient themselves in "a strange and powerful world". The accuracy of their perceived approximation of the truth will therefore have direct consequences on their ability to deal with their environment. Fromm can be understood to define truth as a functional approximation of reality. His vision of optimal truth is described partly in "Man from Himself: An Inquiry into the Psychology of Ethics" (1947), from which excerpts are included below.

> the dichotomy between 'absolute = perfect' and 'relative = imperfect' has been superseded in all fields of scientific thought, where "it is generally recognized that there is no absolute truth but nevertheless that there are objectively valid laws and principles".

> In that respect, "a scientifically or rationally valid statement means that the power of reason is applied to all the available data of observation without any of them being suppressed or falsified for the sake of a desired result". The history of science is "a history of inadequate and incomplete statements, and every new insight makes possible the recognition of the inadequacies of previous propositions and offers a springboard for creating a more adequate formulation."
>
> As a result "the history of thought is the history of an ever-increasing approximation to the truth. Scientific knowledge is not absolute but optimal; it contains the optimum of truth attainable in a given historical period." Fromm furthermore notes that "different cultures have emphasized various aspects of the truth" and that increasing interaction between cultures allows for these aspects to reconcile and integrate, increasing further the approximation to the truth.

Foucault

Truth, for Michel Foucault, is problematic when any attempt is made to see truth as an "objective" quality. He prefers not to use the term truth itself but "Regimes of Truth". In his historical investigations he found truth to be something that was itself a part of, or embedded within, a given power structure. Thus Foucault's view shares much in common with the concepts of Nietzsche. Truth for Foucault is also something that shifts through various episteme throughout history.[59]

Baudrillard

Jean Baudrillard considered truth to be largely simulated, that is pretending to have something, as opposed to dissimulation, pretending to not have something. He took his cue from iconoclasts who he claims knew that images of God demonstrated the fact that God did not exist.[60] Baudrillard wrote in "Precession of the Simulacra":

> The simulacrum is never that which conceals the truth—it is the truth which conceals that there is none. The simulacrum is true.
>
> —Ecclesiastes[61] [62]

Some examples of simulacra that Baudrillard cited were: that prisons simulate the "truth" that society is free; scandals (e.g., Watergate) simulate that corruption is corrected; Disney simulates that the U.S. itself is an adult place. One must remember that though such examples seem extreme, such extremity is an important part of Baudrillard's theory. For a less extreme example, consider how movies usually end with the bad being punished, humiliated, or otherwise failing, thus affirming for viewers the concept that the good end happily and the bad unhappily, a narrative which implies that the status quo and institutionalised power structures are largely legitimate.[60]

Ratzinger

Philosopher and theologian Joseph Ratzinger, before his election as Benedict XVI, commented upon the relationship of truth with tolerance,[63] conscience,[64] freedom,[65] and religion.[63] For him, "beyond all particular questions, the real problem lies in the question of truth."[63]

Ratzinger refers to achievements of the natural sciences as evidence that human reason has the power to know reality and arrive at truth. He also argues that "the modern self-limitation of reason" rooted in Immanuel Kant's philosophy, which views itself incapable of knowing religion and the human sciences such as ethics, leads to dangerous pathologies of religion and pathologies of science.[63] [66] He thinks that this self-limitation, which "amputates" the mind's capacity to answer fundamental questions such as man's origin and purpose, dishonors reason and is contradictory to the modern acclamation of science, whose basis is the power of reason.[63] [66]

In his book *Truth and Tolerance*, Ratzinger argued that truth and love are identical. And if well understood, according to him, this is "the surest guarantee of tolerance."[63]

See also

- Aletheia
- Asha
- Belief
- Confirmation holism
- contextualism
- Contradiction
- Degrees of truth
- Disposition
- Eclecticism
- Imagination
- Independence
- Inquiry
- Interpretation
- Invariance
- Knowledge
- Lie
- Lie-to-children
- List of fallacies
- Normative science
- Objectivity
- Paradox
- Perspectivism
- Philalethia
- Physical symbol system
- Public opinion
- Reality
- Relativism
- Religion
- Religious truth
- Slingshot argument
- Statistical independence
- Tautology (logic)
- Tautology (rhetoric)
- Truthiness
- Truthlikeness
- Two truths doctrine
- Unity of the proposition
- Verisimilitude
- Veritas

Truth in logic

- Fuzzy logic
- Logic
- Logical value
- Modal logic
- Multi-valued logic
- Principle of bivalence
- Truth conditions
- Truth function
- Truth table
- Criteria of truth

Theories of truth

- Anekantavada
- Coherence theory of truth
- Coherentism
- Consensus theory of truth
- Correspondence theory of truth
- Deflationary theory of truth
- Epistemic theories of truth
- Indefinability theory of truth
- Pragmatic theory of truth
- Redundancy theory of truth
- Semantic theory of truth

Major theorists

- Thomas Aquinas
- Aristotle
- J.L. Austin
- Brand Blanshard
- John Dewey
- Hartry Field
- Gottlob Frege
- Jürgen Habermas
- G. W. F. Hegel
- Martin Heidegger
- Augustine of Hippo
- Paul Horwich
- William James
- Harold Joachim
- Saul Kripke
- Friedrich Nietzsche
- Charles Sanders Peirce
- Plato
- Karl Popper
- W.V. Quine
- Frank P. Ramsey
- Bertrand Russell
- Arthur Schopenhauer
- Socrates
- P.F. Strawson
- Alfred Tarski
- Ludwig Wittgenstein

Notes

[1] Merriam-Webster's Online Dictionary, truth (http://m-w.com/dictionary/truth), 2005

[2] see Holtzmann's law for the *-ww-* : *-gg-* alternation.

[3] *A Concise Dictionary of Old Icelandic* (http://www.northvegr.org/zoega/h442.php), Geir T. Zoëga (1910), Northvegr.org

[4] OED on *true* has "Steadfast in adherence to a commander or friend, to a principle or cause, to one's promises, faith, etc.; firm in allegiance; faithful, loyal, constant, trusty; Honest, honourable, upright, virtuous, trustworthy; free from deceit, sincere, truthful " besides "Conformity with fact; agreement with reality; accuracy, correctness, verity; Consistent with fact; agreeing with the reality; representing the thing as it is; Real, genuine; rightly answering to the description; properly so called; not counterfeit, spurious, or imaginary."

[5] Encyclopedia of Philosophy, Supp., "Truth", auth: Michael Williams, p572-573 (Macmillan, 1996)

[6] Blackburn, Simon, and Simmons, Keith (eds., 1999), *Truth*, Oxford University Press, Oxford, UK. Includes papers by James, Ramsey, Russell, Tarski, and more recent work.

[7] Horwich, Paul, *Truth*, (2nd edition, 1988),

[8] Field, Hartry, *Truth and the Absence of Fact* (2001).

[9] Encyclopedia of Philosophy, Vol.2, "Correspondence Theory of Truth", auth: Arthur N. Prior, p223 (Macmillan, 1969) Prior uses Bertrand Russell's wording in defining correspondence theory. According to Prior, Russell was substantially responsible for helping to make correspondence theory widely known under this name.

[10] Encyclopedia of Philosophy, Vol.2, "Correspondence Theory of Truth", auth: Arthur N. Prior, pp. 223-224 (Macmillan, 1969)

[11] Encyclopedia of Philosophy, Vol.2, "Correspondence Theory of Truth", auth: Arthur N. Prior, p224, Macmillan, 1969.

[12] "Correspondence Theory of Truth", in Stanford Encyclopedia of Philosophy (http://plato.stanford.edu/entries/truth-correspondence).

[13] "Correspondence Theory of Truth", in Stanford Encyclopedia of Philosophy (http://plato.stanford.edu/entries/truth-correspondence), (citing De Veritate Q.1, A.1&3; cf. Summa Theologiae Q.16).

[14] *See, e.g.,* Bradley, F.H., "On Truth and Copying", in Blackburn, *et al.* (eds., 1999),*Truth*, 31-45.

[15] Encyclopedia of Philosophy, Vol.2, "Correspondence Theory of Truth", auth: Arthur N. Prior, pp. 223 *ff*. Macmillan, 1969). See especially, section on "Moore's Correspondence Theory", 225-226, "Russell's Correspondence Theory", 226-227, "Remsey and Later Wittgenstein", 228-229, "Tarski's Semantic Theory", 230-231.

[16] Encyclopedia of Philosophy, Vol.2, "Correspondence Theory of Truth", auth: Arthur N. Prior, p. 223 *ff*. Macmillan, 1969). See the section on "Tarski's Semantic Theory", 230-231.

[17] Immanuel Kant, for instance, assembled a controversial but quite coherent system in the early 19th century, whose validity and usefulness continues to be debated even today. Similarly, the systems of Leibniz and Spinoza are characteristic systems that are internally coherent but controversial in terms of their utility and validity.

[18] Encyclopedia of Philosophy, Vol.2, "Coherence Theory of Truth", auth: Alan R. White, p130-131 (Macmillan, 1969)

[19] Encyclopedia of Philosophy, Vol.2, "Coherence Theory of Truth", auth: Alan R. White, p131-133, *see* esp., section on "Epistemological assumptions" (Macmillan, 1969)

[20] Encyclopedia of Philosophy, Vol.2, "Coherence Theory of Truth", auth: Alan R. White, p130

[21] May, Todd, 1993, Between Genealogy and Epistemology: Psychology, politics in the thought of Michel Foucault' with reference to Althusser and Balibar, 1970

[22] *See, e.g.*, Habermas, Jürgen, *Knowledge and Human Interests* (English translation, 1972).

[23] *See, e.g.*, Habermas, Jürgen, *Knowledge and Human Interests* (English translation, 1972), esp. PART III, pp 187 *ff.*

[24] Rescher, Nicholas, *Pluralism: Against the Demand for Consensus* (1995).

[25] Encyclopedia of Philosophy, Vol.5, "Pragmatic Theory of Truth", 427 (Macmillan, 1969).

[26] Peirce, C.S. (1901), "Truth and Falsity and Error" (in part), pp. 716–720 in James Mark Baldwin, ed., *Dictionary of Philosophy and Psychology*, v. 2. Peirce's section is entitled "*Logical*", beginning on p. 718, column 1, and ending on p. 720 with the initials "(C.S.P.)", see Google Books Eprint (http://books.google.com/books?id=Dc8YAAAAIAAJ&pg=PA718). Reprinted, *Collected Papers* v. 5, pp. 565–573.

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[33] Ramsey, F.P. (1927), "Facts and Propositions", Aristotelian Society Supplementary Volume 7, 153–170. Reprinted, pp. 34–51 in F.P. Ramsey, Philosophical Papers, David Hugh Mellor (ed.), Cambridge University Press, Cambridge, UK, 1990

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[40] M. Davis. "Hilbert's Tenth Problem is Unsolvable." *American Mathematical Monthly* 80, pp. 233-269, 1973

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[44] David, Marion (2005). "Correspondence Theory of Truth" (http://plato.stanford.edu/entries/truth-correspondence/#1) in Stanford Encyclopedia of Philosophy
[45] Osman Amin (2007), "Influence of Muslim Philosophy on the West", *Monthly Renaissance* **17** (11).
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[47] Simone van Riet (in Latin). *Liber de philosophia prima, sive Scientia divina*. p. 413.
[48] *Avicenna: The Metaphysics of The Healing*. Michael E. Marmura. Brigham Young University Press. 2005. p. 284.
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[50] "Veritas supra ens fundatur" (Truth is founded on being). *Disputed Questions on Truth*, 10, 2, reply to Obj. 3.
[51] http://www.newadvent.org/summa/1016.htm
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[53] "Die Wahrheit ist die Bewegung ihrer an ihr selbst." *The Phenomenology of Spirit*, Preface, ¶ 48
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External links

- An Introduction to Truth (http://www.galilean-library.org/manuscript.php?postid=43788) by Paul Newall, aimed at beginners.
- Stanford Encyclopedia of Philosophy:
  - Truth (http://plato.stanford.edu/entries/truth/)
  - Coherence theory of truth (http://plato.stanford.edu/entries/truth-coherence/)
  - Correspondence theory of truth (http://plato.stanford.edu/entries/truth-correspondence/)
  - Deflationary theory of truth (http://plato.stanford.edu/entries/truth-deflationary/)
  - Identity theory of truth (http://plato.stanford.edu/entries/truth-identity/)
  - Revision theory of truth (http://plato.stanford.edu/entries/truth-revision/)
  - Tarski's definition of truth (http://plato.stanford.edu/entries/tarski-truth/)
  - Axiomatic theories of truth (http://plato.stanford.edu/entries/truth-axiomatic/)
- Heidegger on Truth (Aletheia) as Unconcealment (http://www.ontology.co/heidegger-aletheia.htm)
- History of Truth: The Greek "Aletheia" (http://www.ontology.co/aletheia.htm)
- History of Truth: The Latin "Veritas" (http://www.ontology.co/veritas.htm)

Aptitude

An **aptitude** is an innate, acquired or learned or developed component of a competency (*the others being knowledge, understanding and attitude*) to do a certain kind of work at a certain level. Aptitudes may be physical or mental. The innate nature of aptitude is in contrast to achievement, which represents knowledge or ability that is gained.[1]

Intelligence and aptitudes

Aptitude and intelligence quotient are related, and in some ways opposite, views of human mental ability. Whereas intelligence quotient sees intelligence as being a single measurable characteristic affecting all mental ability, aptitude refers to one of many different characteristics which can be independent of each other, such as aptitude for military flight or computer programming.[2] This is more similar to the theory of multiple intelligences.

On the contrary, causal analysis with any group of test scores will nearly always show them to be highly correlated. The U.S. Department of Labor's General Learning Ability, for instance, is determined by combining Verbal, Numerical and Spatial aptitude subtests. In a given person some are low and others high. In the context of an aptitude test the "high" and "low" scores are usually not far apart, because all ability test scores tend to be correlated. Aptitude is better applied intra-individually to determine what tasks a given individual is more skilled at performing. Inter-individual aptitude differences are typically not very significant due to IQ differences. Of course this assumes individuals have not already been pre-screened for IQ through some other process such as SAT scores, GRE scores, finishing medical school, etc.

Combined aptitude and knowledge tests

Tests that assess learned skills or knowledge are frequently called achievement tests. However, certain tests can assess both types of constructs. An example that leans both ways is the Armed Services Vocational Aptitude Battery (**ASVAB**), which is given to recruits entering the armed forces of the United States. Another is the SAT, which is designed as a test of aptitude for college in the United States, but has achievement elements. For example, it tests mathematical reasoning, which depends both on innate mathematical ability and education received in mathematics.

See also

- Test (student assessment)
- Skill
- General Learning Ability
- Spatial Visualization Ability

External links

- Cognitive Styles and Implications for the Engineering Curriculum [3]
- Measuring Aptitude [4] - from the Education Resources Information Center Clearinghouse on Tests Measurement and Evaluation, Washington DC.
- Detailed Description and History of Aptitude Testing, Comparison to Other Types of Assessment [5]

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[3] http://fie.engrng.pitt.edu/fie95/4d3/4d32/4d32.htm
[4] http://www.ericdigests.org/pre-9218/aptitude.htm
[5] http://www.theworksuite.com/id15.html

Intelligence

Intelligence is an umbrella term describing a property of the mind including related abilities, such as the capacities for abstract thought, understanding, communication, reasoning, learning, learning from past experiences, planning, and problem solving.

Intelligence is most widely studied in humans, but is also observed in animals and plants. Artificial intelligence is the intelligence of machines or the simulation of intelligence in machines.

Numerous definitions of and hypotheses about intelligence have been proposed since before the twentieth century, with no consensus yet reached by scholars. Within the discipline of psychology, various approaches to human intelligence have been adopted, with the psychometric approach being especially familiar to the general public. Influenced by his cousin Charles Darwin, Francis Galton was the first scientist to propose a theory of general intelligence; that intelligence is a true, biologically-based mental faculty that can be studied by measuring a person's reaction times to cognitive tasks. Galton's research in measuring the head sizes of British scientists and laymen led to the conclusion that head-size is unrelated to a person's intelligence.

Alfred Binet, and the French school of intelligence, believed intelligence was an aggregate of dissimilar abilities, not a unitary entity with specific, identifiable properties.

Definitions

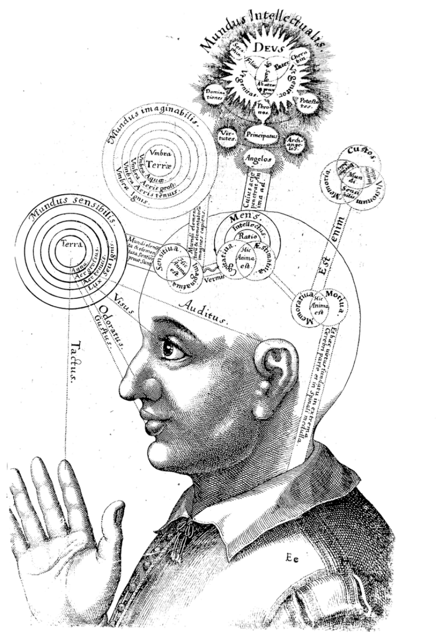
Scientists have proposed two major definitions of intelligence:

1. from *Mainstream Science on Intelligence* (1994), an editorial statement by fifty-two researchers:

   A very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings—"catching on," "making sense" of things, or "figuring out" what to do.[1]

2. from *Intelligence: Knowns and Unknowns* (1995), a report published by the Board of Scientific Affairs of the American Psychological Association:

   Individuals differ from one another in their ability to understand complex ideas, to adapt effectively to the environment, to learn from experience, to engage in various forms of reasoning, to overcome obstacles by



Humans have pondered the nature of intelligence for centuries.

taking thought. Although these individual differences can be substantial, they are never entirely consistent: a given person's intellectual performance will vary on different occasions, in different domains, as judged by different criteria. Concepts of "intelligence" are attempts to clarify and organize this complex set of phenomena. Although considerable clarity has been achieved in some areas, no such conceptualization has yet answered all the important questions, and none commands universal assent. Indeed, when two dozen prominent theorists were recently asked to define intelligence, they gave two dozen, somewhat different, definitions.[2] [3]

Besides the foregoing organizational definitions, these psychology and learning researchers also have defined intelligence as:

Researcher	Quotation
Alfred Binet	Judgment, otherwise called "good sense," "practical sense," "initiative," the faculty of adapting one's self to circumstances ... auto-critique.[4]
David Wechsler	The aggregate or global capacity of the individual to act purposefully, to think rationally, and to deal effectively with his environment.[5]
Cyril Burt	Innate general cognitive ability[6]
Howard Gardner	To my mind, a human intellectual competence must entail a set of skills of problem solving — enabling the individual to resolve genuine problems or difficulties that he or she encounters and, when appropriate, to create an effective product — and must also entail the potential for finding or creating problems — and thereby laying the groundwork for the acquisition of new knowledge.[7]
Linda Gottfredson	The ability to deal with cognitive complexity.[8]
Sternberg & Salter	Goal-directed adaptive behavior.[9]
Reuven Feuerstein	The theory of Structural Cognitive Modifiability describes intelligence as "the unique propensity of human beings to change or modify the structure of their cognitive functioning to adapt to the changing demands of a life situation."[10]

Practical application — Furthermore, in clinical and therapeutic practice, such theoretic and academic definitions of intelligence might not apply to patients with borderline intellectual and adaptive functioning, whose treatments require comprehensive analysis of every diagnostic, testing, educational placement, and psychosocial factor. The eighth (2005) and ninth (2009) editions of the *Kaplan & Sadock's Comprehensive Textbook of Psychiatry*, by Frank John Ninivaggi, MD, address these matters.

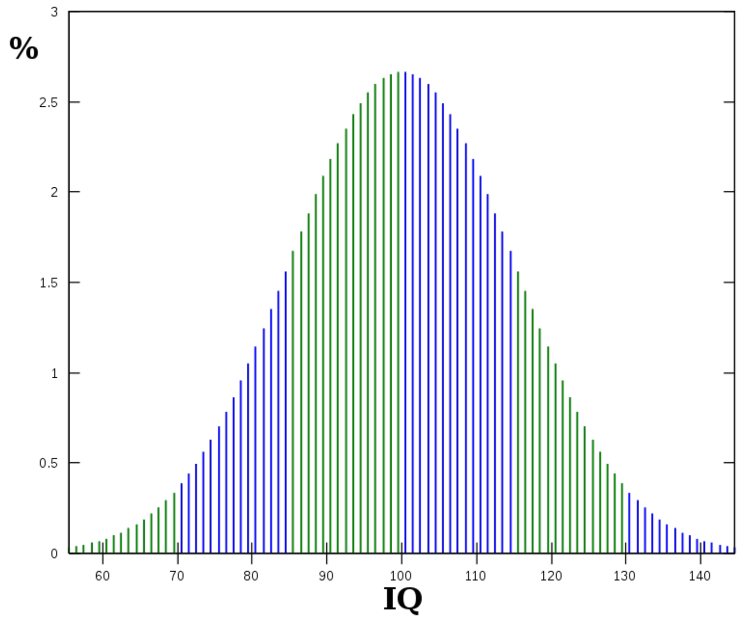
Human intelligence

Theories of human intelligence

A popular theory of intelligence is based on psychometric testing, i.e. intelligence quotient (IQ) tests; however, some researchers' dissatisfaction with traditional IQ tests prompted their developing alternative theories of intelligence suggesting that intelligence results from independent capabilities that uniquely contribute to human intellectual performance.

Psychometric approach

Despite the variety of concepts of intelligence, the approach to understanding intelligence with the most supporters and published research over the longest period of time is based on psychometric testing. Such intelligence quotient (IQ) tests include the Stanford-Binet, Raven's Progressive Matrices, the Wechsler Adult Intelligence Scale and the Kaufman Assessment Battery for Children.



The IQs of a large enough population are calculated so that they conform[11] to a normal distribution.

Charles Spearman is generally credited with defining general intelligence, which he reported in his 1904 *American Journal of Psychology* article titled "'General Intelligence,' Objectively Determined and Measured."[12] [13] [14] Based on the results of a series of studies collected in Hampshire, England, Spearman concluded that there was a common function (or group of functions) across intellectual activities including what he called intelligence (i.e., school rank, which Spearman thought of as "present efficiency" in school courses; the difference between school rank and age, which was conceptualized as "native capacity;" teacher ratings; and peer ratings provided by the two oldest students, which was termed "common sense") and sensory discriminations (i.e., discrimination of pitch, brightness, and weight). This common function became known as "g" or general intelligence.

To objectively determine and measure general intelligence, Spearman invented the first technique of factor analysis (the method of Tetrad Differences) as a mathematical proof of the Two-Factor Theory.[12] [13] [15] The factor analytic results indicated that every variable measured a common function to varying degrees, which led Spearman to develop the somewhat misleadingly named Two-Factor Theory of Intelligence.[12] [15] [16] The Two-Factor Theory of Intelligence holds that every test can be divided into a "g" factor and an "s" factor. The g-factor measures the "general" factor or common function among ability tests. The s-factor measures the "specific" factor unique to a particular ability test. Spearman's g-factor account for positive correlations among any cognitive ability tests. However, the necessary condition for g-factor to exist is routinely violated in correlation matrices of cognitive tests, according to the work by Peter Schönemann and others.[17] .

L.L. Thurstone extended and generalized Spearman's method of factor analysis into what is called the Centroid method and which became the basis for modern factor analysis.[16] [18] Thurstone demonstrated that Spearman's one common factor method (Spearman's method yielded only a single factor) was a special case of his multiple factor analysis. Thurstone's research led him to propose a model of intelligence that included seven orthogonal (unrelated) factors (i.e., verbal comprehension, word fluency, number facility, spatial visualization, associative memory, perceptual speed and reasoning) referred to as the Primary Mental Abilities.[16] [19]

In a critical review of the adult testing literature, Raymond B. Cattell found that a considerable percentage of intelligence tests that purported to measure adult intellectual functioning had all of the trappings of using college students in their development.[20] To account for differences between children/adolescents and adults, which past theory did not address, Cattell proposed two types of cognitive abilities in a revision of Spearman's concept of general intelligence. Fluid intelligence (Gf) was hypothesized as the ability to discriminate and perceive relations (e.g., analogical and syllogistic reasoning), and crystallized intelligence (Gc) was hypothesized as the ability to discriminate relations that had been established originally through Gf, but no longer required the identification of the relation (commonly assessed using information or vocabulary tests). In addition, fluid intelligence was hypothesized to increase until adolescence and then to slowly decline, and crystallized intelligence increases gradually and stays relatively stable across most of adulthood until it declines in late adulthood.

With his student John L. Horn, Cattell indicated that Gf and Gc were only two among several factors manifest in intelligence tests scores under the umbrella of what became known as Gf/Gc Theory.[21] General visualization (Gv; visual acuity, depth perception), general fluency (F, facility in recalling words), general speediness (Gs; performance on speeded, simple tasks) were among several cognitive ability factors added to Gf/Gc Theory.

J.P. Guilford sought to more fully explore the scope of the adult intellect by providing the concept of intelligence with a strong, comprehensive theoretical backing.[22] [23] The Structure-of-Intellect model (SI model) was designed as a cross classification system with intersections in the model providing the basis for abilities similar to Mendeleev's periodic table in chemistry. The three-dimensional cube—shaped model includes five content categories (the way in which information is presented on a test; visual, auditory, symbolic, semantic, and behavioral), six operation categories (what is done on a test; evaluation, convergent production, divergent production, memory retention, memory recording, and cognition), and six product categories (the form in which information is processed on a test; units, classes, relations, systems, transformations, and implications). The intersection of three categories provides a frame of reference for generating one or more new hypothetical factors of intelligence.

John B. Carroll re-analyzed 461 datasets in the single most comprehensive study of cognitive abilities.[14] [24] This analysis led him to propose the Three Stratum Theory, which is a hierarchical model of intellectual functioning. The strata represent three different levels of generality over the domain of cognitive abilities. At the bottom is the first stratum, which is represented by narrow abilities that are highly specialized (e.g., induction, spelling ability). The second stratum is represented by broad abilities that include moderate specializations in various domains. Carroll identified eight second-stratum factors: fluid intelligence, crystallized intelligence, general memory and learning, broad visual perception, broad auditory perception, broad retrieval ability, broad cognitive speediness, and processing speed (reaction time decision speed). Carroll has noted the similarity of his second stratum abilities and the Gf/Gc factors, although the Three-Stratum Theory does not incorporate the developmental trajectories associated with Gf/Gc Theory. Carroll accepted Spearman's concept of general intelligence, for the most part, as a representation of the uppermost third stratum.

More recently, an amalgamation of the Gf-Gc theory of Cattell and Horn with Carroll's Three-Stratum theory has led to the Cattell-Horn-Carroll (CHC) Theory of cognitive abilities.[25] CHC researchers have produced numerous studies that have influenced diagnostic issues and test development.[26]

Intelligence tests are widely used in educational, business, and military settings due to their efficacy in predicting behavior. *g* is highly correlated with many important social outcomes—individuals with low IQs are more likely to be divorced, have a child out of marriage, be incarcerated, and need long-term welfare support, while individuals with high IQs are associated with more years of education, higher status jobs and higher income.[27] Intelligence is significantly correlated with successful training and performance outcomes, and *g* is the single best predictor of successful job performance.[28]

Controversies

IQ tests were originally designed to identify mentally "defective" children.[29] The inventors of the IQ did not necessarily believe they were measuring fixed intelligence. Despite this, critics argue that intelligence tests have been used to support nativistic theories which view intelligence as a qualitative object with a relatively fixed quantity.[30]

Critics of the psychometrics point out that intelligence is often more complex and broader in conception than what is measured by IQ tests. Furthermore, skeptics argue that even though tests of mental abilities are correlated, people still have unique strengths and weaknesses in specific areas. Consequently they argue that psychometric theorists over-emphasize *g*, despite the fact that *g* was defined so as to encompass all inter-correlated capabilities and skills.

Researchers in the field of human intelligence have encountered a considerable amount of public concern and criticism—much more than scientists in other areas normally receive. A number of critics have challenged the relevance of psychometric intelligence in the context of everyday life. There have also been controversies over genetic factors in intelligence, particularly questions regarding the relationship between race and intelligence and sex and intelligence.[31] Another controversy in the field is how to interpret the increases in test scores that have occurred over time, the so-called Flynn effect.

Stephen Jay Gould was one of the most vocal critics of intelligence testing. In his book *The Mismeasure of Man* Gould argued that intelligence could not be quantified to a single numerical entity. He also challenged the hereditarian viewpoint on intelligence. Many of Gould's criticisms were aimed at Arthur Jensen, who responded that his work had been misrepresented.[32] Gould also investigated the methods of 19th-century craniometry. Jensen stated that drawing conclusions from early intelligence research is like condemning the auto industry by criticizing the performance of the Model T.

Multiple intelligences

Howard Gardner's theory of multiple intelligences is based on studies not only of normal children and adults but also by studies of gifted individuals (including so-called "savants"), of persons who have suffered brain damage, of experts and virtuosos, and of individuals from diverse cultures. This led Gardner to break intelligence down into at least eight different components: logical, linguistic, spatial, musical, kinesthetic, interpersonal, intrapersonal in 1983 and naturalist intelligences added in 1999. He argues that psychometric tests address only linguistic and logical plus some aspects of spatial intelligence. A major criticism of Gardner's theory is that it has never been tested, or subjected to peer review, by Gardner or anyone else, and indeed that it is unfalsifiable.[33]

Triarchic theory of intelligence

Robert Sternberg proposed the triarchic theory of intelligence to provide a more comprehensive description of intellectual competence than traditional differential or cognitive theories of human ability.[34] The triarchic theory describes three fundamental aspects of intelligence. Analytic intelligence comprises the mental processes through which intelligence is expressed. Creative intelligence is necessary when an individual is confronted with a challenge that is nearly, but not entirely, novel or when an individual is engaged in automatizing the performance of a task. Practical intelligence is bound in a sociocultural milieu and involves adaptation to, selection of, and shaping of the environment to maximize fit in the context. The triarchic theory does not argue against the validity of a general intelligence factor; instead, the theory posits that general intelligence is part of analytic intelligence, and only by considering all three aspects of intelligence can the full range of intellectual functioning be fully understood.

More recently, the triarchic theory has been updated and renamed the Theory of Successful Intelligence by Sternberg.[35] [36] Intelligence is defined as an individual's assessment of success in life by the individual's own (idiographic) standards and within the individual's sociocultural context. Success is achieved by using combinations of analytical, creative, and practical intelligence. The three aspects of intelligence are referred to as processing skills. The processing skills are applied to the pursuit of success through what were the three elements of practical intelligence: adapting to, shaping of, and selecting of one's environments. The mechanisms that employ the processing skills to achieve success include utilizing one's strengths and compensating or correcting for one's weaknesses.

Sternberg's theories and research on intelligence remain contentious within the scientific community.[37] [38] [39] [40]

Developmental approach

Jean Piaget[41] was the founder of the developmental approach to the study of intelligence. According to his theory of cognitive development, intelligence is the basic mechanism of ensuring equilibrium in the relations between the person and the environment. This is achieved through the actions of the developing person on the world. At any moment in development, the environment is assimilated in the schemes of action that are already available and these schemes are transformed or accommodated to the peculiarities of the objects of the environment, if they are not completely appropriate. Thus, the development of intelligence is a continuous process of assimilations and accommodations that lead to increasing expansion of the field of application of schemes, increasing coordination between them, increasing interiorization, and increasing abstraction. Piaget described four main periods or stages in the development towards completely equilibrated thought and problem solving. In the sensorimotor stage (0–2 years), thought is based on perceptions and external actions and their coordination. In the preoperational stage, sensorimotor schemes are internalized and thought occurs mentally rather than externally, through the manipulation of representations and symbols that stand for sensorimotor schemes and objects.[42]

At the beginning, however, mental schemes are not coordinated. As a result, systematic logical reasoning is not possible (that, for example, A = C, if A = B and B = C). When mental schemes are coordinated, thinking enters the concrete operational stage. In this period, thinking is logical, but limited to the concrete aspects of the world. That is, children can grasp several important aspects of the world, such as the conservation of number, matter, length, weight, volume, etc. despite external transformation. Gradually, concrete operational schemes are coordinated with each other and cognitive development enters the final formal operational stage. In this period reality is subsumed to possibilities and reasoning becomes formal. As a result, abstract scientific concepts such as the concept of inertia, energy, algebra, and proportionality can be grasped and scientific experiments can be designed. All in all, for Piaget intelligence is not the same at different ages. It changes qualitatively, thereby allowing access to different levels of organization of the world. Research shows that Piagetian intelligence is correlated but it is not identical with psychometric intelligence and IQ.[42]

The neo-Piagetian theories of cognitive development[43] advanced by Case, Demetriou, Halford, and Pascual-Leone, attempted to integrate Piaget's theory with cognitive and differential theories of cognitive organization and development. Their aim was to better account for the cognitive factors of development and for intra-individual and inter-individual differences in cognitive development. They suggested that development along Piaget's stages is due to increasing processing efficiency which is defined in terms of speed of processing and working memory capacity. Moreover, Demetriou's theory ascribes an important role to hypercognitive processes of self-recording, self-monitoring, and self-regulation and it recognizes the operation of several relatively autonomous domains of thought.

Overall, this approach suggests that there indeed is a general intelligence factor. This factor is geared on general processing efficiency functions that enable humans to represent and process information, that processing involves general inferential processes that are gradually constructed, and self-awareness and reflection are instrumental in this construction. The general understanding and problem solving ability associated with this factor changes qualitatively with age and this change is related to the succession of Piagetian stages. At the same time, individual differences in the state of the general efficiency factors may cause differences in the rate of intellectual development of different individuals and these differences may be reflected in psychometric measures of cognitive ability, such as the IQ tests. Moreover differences between individuals may come from differences in their predispositions or facility related to different domains of knowledge and problem solving.[44]

Emotional intelligence

Daniel Goleman and several other researchers have developed the concept of emotional intelligence and claim it is at least as "important" as traditionally proposed components of intelligence. These theories grew from observations of human development and of brain injury victims who demonstrate an acute loss of a particular cognitive function—e.g. the ability to think numerically, or the ability to understand written language—without showing any loss in other cognitive areas.

Many researchers believe that emotional intelligence is a composite of general intelligence and agreeableness, one of the five dimensions of personality in the five-factor model of personality. In this model, an emotionally intelligent person would score higher than average in both dimensions, and vice versa. Moreover, an emotionally intelligent person cannot score high on only one of the two traits. For example, an individual with low general mental ability and high agreeableness would be impaired in his ability to produce emotionally intelligent behavior despite his intentions, while an individual with high general mental ability and low agreeableness would be perfectly capable of being emotionally intelligent, but not inclined to do so.

PASS theory

PASS theory has been offered as an alternative to general intelligence, and is based on a description of neuropsychological processes.[45] [46] [47] These authors suggested that a unidimensional model with just intelligence fails to assist researchers and clinicians who study learning disabilities, disorders of attention, mental retardation, and interventions designed for special populations who face those challenges. The PASS model covers four kinds of competencies that are associated with areas of the brain.

1. The planning processes involve decision making, problem solving, and performing activities and requires goal setting and self-monitoring.
2. The attention/arousal component involves selectively attending to a particular stimulus, ignoring distractions, and maintaining vigilance.
3. Simultaneous processing involves the integration of stimuli into a group and requires the observation of relationships.
4. Successive processing involves the integration of stimuli into serial order.

The planning and attention/arousal components comes from structures located in the frontal lobe, and the simultaneous and successive processes come from structures located in the posterior region of the cortex.

Empirical evidence

IQ proponents have claimed that IQ's predictive validity has been demonstrated, for example in predicting non-academic outcomes such as job performance (see IQ), and that the various multiple intelligence theories have little or no such support. Meanwhile, it has been claimed that the relevance and existence of multiple intelligences have not been borne out when tested. A set of ability tests that do not correlate together would support the claim that multiple intelligences are independent of each other.

Evolution of intelligence

Our hominid and human ancestors evolved large and complex brains exhibiting an ever-increasing intelligence through a long and mostly unknown evolutionary process. This process was either driven by the direct adaptive benefits of intelligence,[48] or, alternatively, driven by its indirect benefits within the context of sexual selection as a reliable signal of genetic resistance against pathogens.[49]

Factors affecting intelligence

Intelligence is an ill-defined, difficult to quantify concept. Accordingly, the IQ tests used to measure intelligence provide only approximations of the posited "real" intelligence. In addition, a number of theoretically unrelated properties are known to correlate with IQ such as race, gender and height but since correlation does not imply causation the true relationship between these factors is uncertain. Factors affecting IQ may be divided into biological and environmental.

Biological

The biological factors that correlate with IQ include ratio of brain weight to body weight and the volume and location of gray matter tissue in the brain. However, the basic mechanisms by which the brain produces complex phenomena such as intelligence are still poorly understood.[50] Lesion studies indicate that general intelligence "draws on connections between regions that integrate verbal, visuospatial, working memory, and executive processes."[51]

Because intelligence appears to be at least partly dependent on brain structure and the genes shaping brain development, it has been proposed that genetic engineering could be used to enhance the intelligence of animals, a process sometimes called biological uplift in science fiction. Experiments on mice have demonstrated superior ability in learning and memory in various behavioral tasks.[52]

Environmental

Evidence suggests that family environmental factors may have an effect upon childhood IQ, accounting for up to a quarter of the variance. Other variance in IQ results from environmental influences not shared by siblings who grow up in the same home. Another important influence on IQ that was often neglected in earlier human genetic studies is the "maternal effect" of the prenatal environment of the mother's womb.[53] In the context of follow-up research on the nature versus nurture debate, it is still unclear whether the "nature" component is more important than the "nurture" component in explaining IQ variance in the general population.[54]

There are indications that in middle age intelligence is influenced by life style choices (e.g. long working hours[55]).

Cultural factors also play a role in intelligence. For example, on a sorting task to measure intelligence, Westerners tend to take a taxonomic approach while the Kpelle people take a more functional approach. For example, instead of grouping food and tools into separate categories, a Kpelle participant stated "the knife goes with the orange because it cuts it."[56]

Ethical issues

Conscious efforts to influence intelligence raise ethical issues. Transhumanist theorists study the possibilities and consequences of developing and using techniques to enhance human abilities and aptitudes, and individuals ameliorating what they regard as undesirable and unnecessary aspects of the human condition; eugenics is a social philosophy which advocates the improvement of human hereditary traits through various forms of intervention.[57] Eugenics has variously been regarded as meritorious or deplorable in different periods of history, falling greatly into disrepute after the defeat of Nazi Germany in World War II. Policies promoted on supposed eugenic grounds usually favor the ethnic group in political authority, without regard to evidence of genetic superiority. For example, Jewish people were disfavored by the Nazis even though Jews in Germany had conspicuous achievements in the arts and sciences.

Neuroethics considers the ethical, legal and social implications of neuroscience, and deals with issues such as the difference between treating a human neurological disease and enhancing the human brain, and how wealth impacts access to neurotechnology. Neuroethical issues interact with the ethics of human genetic engineering.

Animal and plant intelligence

The common Chimpanzee can use tools. This chimpanzee is using a stick in order to get food.

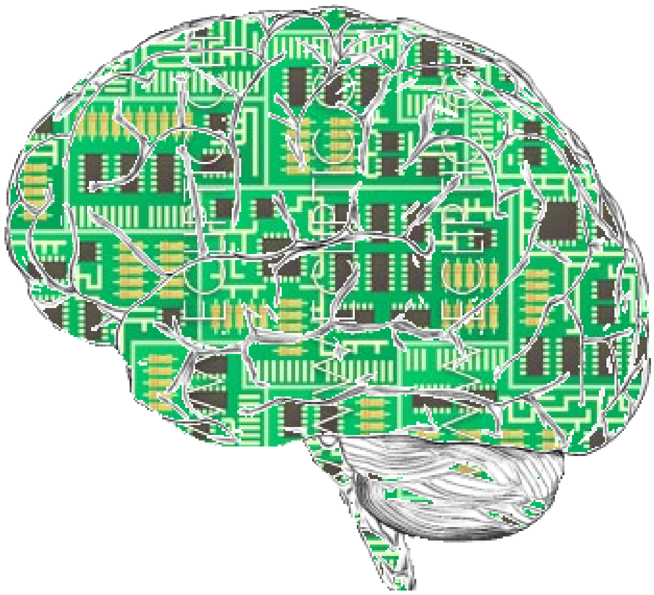
Although humans have been the primary focus of intelligence researchers, scientists have also attempted to investigate animal intelligence, or more broadly, animal cognition. These researchers are interested in studying both mental ability in a particular species, and comparing abilities between species. They study various measures of problem solving, as well as mathematical and language abilities. Some challenges in this area are defining intelligence so that it means the same thing across species (e.g. comparing intelligence between literate humans and illiterate animals), and then operationalizing a measure that accurately compares mental ability across different species and contexts.

Wolfgang Köhler's pioneering research on the intelligence of apes is a classic example of research in this area. Stanley Coren's book, *The Intelligence of Dogs* is a notable popular book on the topic.[58] Nonhuman animals particularly noted and studied for their intelligence include chimpanzees, bonobos (notably the language-using Kanzi) and other great apes, dolphins, elephants and to some extent parrots and ravens. Controversy exists over the extent to which these judgments of intelligence are accurate.

Cephalopod intelligence also provides important comparative study. Cephalopods appear to exhibit characteristics of significant intelligence, yet their nervous systems differ radically from those of most other notably intelligent life-forms (mammals and birds).

It has been argued that plants should also be classified as being intelligent based on their ability to sense the environment and adjust their morphology, physiology and phenotype accordingly.[59] [60]

Artificial intelligence


In the field of artificial intelligence there is no consensus on how closely the brain should be simulated.

Artificial intelligence (or AI) is both the intelligence of machines and the branch of computer science which aims to create it, through "the study and design of intelligent agents"[61] or "rational agents", where an intelligent agent is a system that perceives its environment and takes actions which maximize its chances of success.[62] Achievements in artificial intelligence include constrained and well-defined problems such as games, crossword-solving and optical character recognition. General intelligence or strong AI has not yet been achieved and is a long-term goal of AI research.

Among the traits that researchers hope machines will exhibit are reasoning, knowledge, planning, learning, communication, perception, and the ability to move and manipulate objects.[61] [62]

Intelligence in culture and arts

The concept of intelligence has been treated in many works:

- Flowers for Algernon, a book written by Daniel Keyes and published in 1966.

See also

- Active intellect
- Artificial Intelligence
- Downing effect
- Educational psychology
- Evolution of human intelligence
- Fertility and intelligence
- Flynn effect
- History of the race and intelligence controversy
- Individual differences psychology
- Intellectual giftedness
- Intelligence quotient
- Knowledge
- Passive intellect
- Race and intelligence
- Religiosity and intelligence
- Situational intelligence
- Systems intelligence

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External links

- APA Task Force Examines the Knowns and Unknowns of Intelligence (http://web.archive.org/web/20041130090438/http://www.apa.org/releases/intell.html) - *American Psychological Association*, Press release
- The cognitive-psychology approach vs. psychometric approach to intelligence (http://www.americanscientist.org/template/AssetDetail/assetid/24538/page/1) - *American Scientist* magazine
- History of Influences in the Development of Intelligence Theory and Testing (http://www.indiana.edu/~intell/map.shtml) - Developed by Jonathan Plucker at Indiana University

Scholarly journals and societies

- *Intelligence* (journal homepage (http://www.elsevier.com/locate/intell))
- International Society for Intelligence Research (homepage (http://www.isironline.org/))

Skill

A **skill** is the learned capacity to carry out pre-determined results often with the minimum outlay of time, energy, or both. Skills can often be divided into domain-general and domain-specific skills. For example, in the domain of work, some general skills would include time management, teamwork and leadership, self motivation and others, whereas domain-specific skills would be useful only for a certain job. Skill usually requires certain environmental stimuli and situations to assess the level of skill being shown and used.

People need a broad range of skills in order to contribute to a modern economy and take their place in the technological society of the twenty-first century. An ASTD study showed that through technology, the workplace is changing, and so are the skills that employees must have to be able to change with it. The study identified 16 basic skills (Carnevale, 1990) that the workplace of the future would need in the employee of the future.

General skills

Learning to learn

Learning is an integral part of everyday life. The skill of knowing how to learn is a must for everybody and is the key to acquiring new skills and sharpening the ability to think through problems face challenges. It opens the door to other learning. Study smarter - not harder. A secondary benefit of learning how to learn is that it empowers the learner's ability to develop a measurable task repeatedly.

Foundation skills

From the employer's perspective, the skill of knowing how to learn is cost-effective because it can mitigate the cost of retraining efforts. When workers use efficient learning strategies, they absorb and apply training more quickly, saving their employers money and time. When properly prepared, employees can use learning-to-learn techniques to distinguish between essential and nonessential information, discern patterns in information, and pinpoint the actions necessary to improve job performance. Many employers - particularly those dealing with rapid technological change see the learning-to-learn skill as an urgent necessity. Productivity, innovation, and competitiveness all depend on developing the workers' learning capability. Machinery and processes are transferable between companies and countries, but it is the application of human knowledge to technology and systems that provides the competitive edge.

Basic skills competence

The inability of large numbers of new workers to meet reading, writing, or computational (simple mathematics) standards is an economic and competitive issue. This forces employers to spend more on these critical competence skills. The majority of workers are literate and numerate but frequently, cannot use these skills effectively because they are rusty when called upon to use mathematical principles they have not used for 20 years, because they must use the skills in a context different from the one in which they originally learned them, or because they do not understand how to expand or apply the skill.

Reading

Reading has historically been considered the fundamental vocational skill for a person to get, keep, get ahead, or to change jobs. One educational assessment by Kirsch and Jungeblut in 1986, indicates that there is a large nationwide population of intermediate literates who only have fourth to eighth grade literacy equivalency (but are high school graduates) and who have not obtained a functional or employable literacy level.

Writing

Writing is consistently ranked among the highest priorities for job applicants and employees. One study states that more than 50 percent of the business respondents identified writing skill deficiencies in secretarial, skilled, managerial, supervisory, and bookkeeping personnel.

Computation

Because of technology, simple mathematical computation is important as employers focus on an employee's ability to compute at higher levels of sophistication. The introduction of sophisticated management and quality control approaches demand higher mathematical skills. Ironically, as occupational skill-level requirements climb, higher educational dropout rates and worsening worker deficiencies in computational skills are appearing (Brock, 1987; Kirsch and Jungeblut, 1986; Semerad, 1987). Employers complain particularly about miscalculations of decimals and fractions, resulting in expensive production errors. Employees must calculate correctly to conduct inventories, complete accurate reports of production levels, measure machine parts or specifications so that medium-to-high levels of mathematics skills are required across job categories. The business effect of math skill deficiencies is bottom line losses.

Communication skills

Formal education in communication has been directed at reading and writing skills that are used least in the workplace. Most have only one or two years in speech related courses and no formal training in listening. Workers who can express their ideas orally and who understands verbal instructions make fewer mistakes, adjust more easily to change, and more readily absorb new ideas than those who do not. Thus career development is enhanced by training in oral communication and listening because these skills contribute to an employee's success in all of the following areas: interviewing, making presentations at or conducting meetings; negotiating and resolving conflict; selling; leading; being assertive; teaching or coaching others; working in a team; giving supervisors feedback about conversations with customers; and retraining. Employees spend most of the day communicating, and the time they spend will increase as robots, computers, and other machines take over mundane, repetitive jobs.

Oral

Skill in oral communication is a key element of good customer service. More than 76 million workers (in the USA) are in the service sector and companies that provide excellent service tend to stay far ahead of their competitors. To provide good service, all employees (not just designated sales and marketing employees) must learn how to talk and listen to customers, handle complaints and solve their problems.

Listening

As workers go up the corporate ladder, the listening time increases so that top managers spend as much as 65 percent of their day listening (Keefe, 1971). Because most people have had no training in this critical skill, poor listening habits cost hundreds of millions of dollars each year in productivity lost through misunderstandings and mistakes. At the rate of one $15 mistake per U.S. employee per year, the annual cost of poor listening would be more than a billion dollars.

Problem-solving

Problem-solving skills include the ability to recognize and define problems, invent and implement solutions, and track and evaluate results. Creative thinking not only requires the ability to understand problem-solving techniques, but also to transcend logical and sequential thinking, making the leap to innovation. Unresolved problems create dysfunctional relationships in the workplace. Ultimately, they become impediments to flexibility and in dealing with strategic change in an open-ended and creative way.

Creative thinking

New approaches to problem-solving, organizational design, and product development all spring from the individual capacity for creative thinking. At work, creative thinking is generally expressed through the process of creative problem solving. Increasingly, companies are identifying creative problem solving as critical to their success and are instituting structured approaches to problem identification, analysis, and resolution. Creative solutions help the organization to move forward toward strategic goals. Organizational strategy is an example of creative thinking.

Self-esteem

Another key to effectiveness is good personal management. Self-esteem, motivation/goal setting, and employability/career development skills are critical because they impact individual morale which in turn plays a significant role in an institutions ability to achieve bottom line results. Employers have felt the pressure to make provisions to address perceived deficiencies in these skill areas because they realize that a work force without such skills is less productive. Conversely, solid personal management skills are often manifested by efficient integration of new technology or processes, creative thinking, high productivity, and a pursuit of skill enhancement. Unfortunately, problems related to these skill areas have increased primarily because entry-level applicants are arriving with deficiencies in personal management skills. On the job, the lack of personal management skills affects hiring and training costs, productivity, quality control, creativity, and ability to develop skills to meet changing needs. This presents a series of roadblocks that slow or halt an organizations progress. An organization with such difficulties cannot plan accurately for its future to integrate new technology, establish new work structures, or implement new work processes.

Motivation/goal setting

Motivation is the combination of desire, values, and beliefs that drives you to take action. These three motivating factors, and/or lack of them, are at the root of why people behave the way they do. Because you ultimately control your values, beliefs, and desires, you can influence your motivations. This means, if you consider something important and assign value to it, you are more likely to do the work it takes to attain the goal. When motivation originates from an internal source and is combined with a realistic goal and circumstance, the odds of a good outcome are greatly increased.

Employability/career development

One of the keys to success in today’s world of work is career self-reliance — the ability to actively manage worklife in a rapidly changing environment and the attitude of being self-employed whether inside or outside an organization. Acquiring the skills and knowledge to become career self-reliant will enable employees to survive and even thrive in times of great change.

Group effectiveness

The move toward participative decision making and problem solving inevitably increases the potential for disagreement, particularly when the primary work unit is a peer team with no supervisor. This puts a premium on developing employees group effectiveness skills.

Interpersonal

Interpersonal skills training can help employees recognize and improve their ability to determine appropriate self-behaviour, cope with undesirable behaviour in others, absorb stress, deal with ambiguity, structure social interaction, share responsibility, and interact more easily with others. Teamwork skills are critical for improving individual task accomplishment because practical innovations and solutions are reached sooner through cooperative behaviour.

Negotiation and teamwork

Negotiation skills are critical for the effective functioning of teams as well as for individual acceptance in an organization. Change strategies are usually dependent upon the ability of employees to pull together and refocus on the new common goal. Carnevale wrote in a previous book that there are two ways to increase productivity. "The first is by increasing the intensity with which we utilize (human) resources (working harder), and the second is by increasing the efficiency with which we mix and use available resources (working smarter)."

Influence

The new competitive standards affect organizational structures, requiring a move away from top- down systems and toward more flexible networks and work teams. Technical changes result in new work processes and procedures. These require constant updating of employer-specific technical knowledge. In a world of rapid change, obsolescence is an interminable danger. As technology replaces more of the hands-on work, more employees will be dedicated to service functions where they will spend more time face-to-face with co-workers and clients. Organizational formats in the New Economy require more general skills. Interpersonal skills, communications skills and effective leadership skills are required by more and more non-supervisory employees. Managers in the New Economy relinquish control of work processes to work teams and will need to provide integration through leadership and monitoring.

Organizational

To be effective, employees need a sense of how the organization works and how the actions of each individual affect organizational and strategic objectives. Skill in determining the forces and factors that interfere with the organizations ability to accomplish its tasks can help the worker become a master problem solver, an innovator, and a team builder. Organizational effectiveness skills are the building blocks for leadership. A proactive approach toward increasing organizational effectiveness skills through training reflects the commitment to shared leadership concepts operating in the organization. Implementing shared leadership values has a positive impact on productivity. When leadership functions are dispersed, those who perform in leadership roles willingly take on the responsibility for creating and communicating the vision of the organization and what its work groups should accomplish. By their proximity, they are also better able to create and communicate the quality of the work environment necessary to realize that vision. One approach is the superteam which is defined as a high performing team which produces outstanding achievements. Leaders of superteams spend as much time anticipating the future as they do managing the present by thinking forward to, and talking to others about their goal, for it is this that provides the team with its purpose and direction (Hastings, Bixby, and Chaudhry-Lawton, 1986). Deploying visionary leaders improves institutional response time to changing and increasingly complex external environment factors that affect the organization's ability to operate effectively.

Leadership

At its most elementary level, leadership means that one person influences another. An organization that supports the concepts of shared leadership encourages employees at all levels to assume this role where it is appropriate. The function of leadership include stating basic values, announcing goals, organizing resources, reducing tensions between individuals, creating coalitions, coalescing workers, and encouraging better performance. There is a direct correlation between the implementation of shared leadership practice and product improvement, higher morale, and innovative problem solving, which leads to a more hospitable environment for instituting change. Top management cannot make the system work without employees taking on shared leadership roles. A great many people must be in a state of psychological readiness to take leaderlike action to improve the functioning at their levels. Historically, the roots of business failure can often be traced to inadequate training in and attention to the importance of leadership as a basic workplace skill. Too frequently, companies designate leaders without providing proper evaluation and training to ensure that they are qualified to assume leadership roles.

Examples

- Academic skills
  - Reading
  - Logic
  - Critical thinking
- Interpersonal communication
  - Speech: listening, talking
  - Nonverbal communication
  - Literacy: writing, reading
- Motor skills
  - Walking, arts and crafts, craft, sport
- Skilled labor
- Innovation skill

Miscellaneous

- Charisma

- Perception
- Persuasion
- Procedural memory, knowledge, expertise, fluency
- Profession
- Theory of multiple intelligences
- Thinking and intelligence, IQ

See also

- Competence (disambiguation)
- Deskilling
- Dreyfus model of skill acquisition
- Dunning–Kruger effect, the tendency for incompetent people to grossly overestimate their skills
- Four stages of competence
- Game of skill
- Habit (psychology)
- Human development theory
- Incompetence
- Individual capital
- Learning
- Online skill-based game
- Soft skills
- Transferable skills analysis

References

External links

- Skills Development: Attitudes and Perceptions (http://www.skillsdevelopment.org/default.aspx?page=350) - City & Guilds Centre for Skills Development
- American Society for Training & Development (http://www.astd.org)
- Online Courses with Skill Orientation (http://www.schoox.com/skills/skills.php)
- Australian National Training Authority (http://www.dest.gov.au/sectors/training_skills)
- NCVER's Review of generic skills for the new economy (http://www.ncver.edu.au/research/proj/nr0024.pdf)
- SKILLS EU Research Integrated Project (http://www.skills-ip.eu/)

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