efficiencies, and behavioral flexibility or just because they have not experienced any necessity to achieve such an evolution in their natural environments.

At this moment, the cognitive processes that lead to the invention and modification of new tool-use behavior remain for further investigation. Since the first observation of wild chimpanzees was achieved by Jane Goodall in 1960, the study of nonhuman animals' tool use does not have a long history, and we have not accumulated enough examples of invention and modification of new tool-use behaviors. It is difficult to clarify the mechanism even in human cases and much more difficult for human cases involving fossils because it is impossible to identify the "first" appearance from fossil records. Despite these difficulties, however, investigation of the cognitive processes underlying the invention and modification of tool-use behavior is worthwhile, as it deepens our understanding of how we can reach the production of a new idea, the origins of creativity.

Cross-References

▶ Adaptive Creativity and Innovative Creativity
▶ Analogies and Analogical Reasoning in Invention
▶ Cognition of Creativity
▶ How does Material Culture Extend the Mind?
▶ In Search of Cognitive Foundations of Creativity
▶ Invention Versus Discovery
▶ Patterns of Technological Evolution
▶ Psychology of creativity
▶ Radical invention

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Invention Versus Discovery

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Synonyms

Discover: Observe, Find, Unveil; Invent: Devise, Create, Innovate

The concept of discovery indicates the process of finding something that exists but that is not known or recognized yet. The concept of invention, on the other hand, indicates the process of devising something that does not exist.

The two concepts of discovery and invention form a dichotomy that portrays a central tension in epistemology. They highlight two different angles from which one can look at the relation between theory and experience.

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Introduction

The relation between theory and experience has always been an issue of paramount importance in both philosophy and science. The first modern stand on this issue traces back to Francis Bacon, the father of the experimental method. According to Bacon, scientific theories are obtained directly by induction from observation: Scientific theories exist in nature and scientists limit themselves to discover them through observation. According to Bacon, science is a process that consists in a gradual and linear accumulation of truths about nature. This epistemological position can be conveniently indicated as the *discoverist* position.

The discoverist position has been challenged by a major breakthrough in physics: the refutation of classical mechanics. For more than 200 years, the Newtonian description of nature allowed scientists to obtain predictions that matched accurately empirical results both in the terrestrial and in the celestial domain. The crisis of Newton's theory came as a shock for all scientific disciplines. This shock affected also the epistemological foundations of science. In particular, the fact that classical mechanics, which had been considered for centuries as the true description of the universe, was superseded by relativistic and quantum mechanics challenged the very idea that science is about the accumulation of truths about nature.

The shift from classical to relativistic and quantum mechanics determined a major *epistemological shift*: the shift from the discoverist position to what can be named the *inventionist* position. This shift moves from the idea that science is made of truths that are discovered by induction from observation to the idea that science is about the construction of conjectures that are not obtained directly through experience and that cannot be definitively verified on the basis of experience itself. The dichotomy *inventionism/discoverism* can be used to highlight the tension between the two positions on the status of science that have characterized the scientific debate after the crisis of classical mechanics.

The Discoverist Position

The discoverist position has its roots in the ancient and medieval philosophy and relies on the idea that the ultimate structure of nature can be eventually known beneath the fallacious appearances. As already mentioned above, Bacon embodies such an epistemological position. Bacon's picture of science rests upon the idea that natural laws are obtained by induction from simple observation. Coherently, Bacon (1610) insists that the experimenter should avoid all theoretical anticipations that Bacon calls *idola*. The term *idolum* comes from the Greek *eidolon*, meaning image or phantom. Bacon uses this term to convey the idea that scientists should not observe reality through theoretical constructs: Scientists should simply stick to the data obtained from experience, which Bacon regards as completely objective and as the only source of knowledge. In the proper experimental phase, the experimenter should collect data and organize them in what he calls *tabulae*, which can be regarded as the forerunners of the contemporary databases. The experimenter should eventually derive by induction general laws from the *tabulae*. Two centuries after Bacon, John Stuart Mill (1843) further elaborated the discoverist view of science. Mill stated that induction is a necessary tool to acquire knowledge: It is the only genuine method that allows us to obtain general theories and to justify them. In a way, the discoverist view can be epitomized by the idea that science can eventually remove Schopenhauer's *veil of Maya* and reveal the truth about reality.

The idea that laws truly representing nature can be extracted simply and immediately from experimental data stands on the assumption that these laws are isomorphic to the reality to which they refer. Translated in more contemporary terms (see, e.g., Hastie et al. 2003), this assumption equates to the idea that the real system under observation belongs to the model space. This assumption is necessary if a scientific model is deemed to converge, when sufficient experimental data are available, to the real system itself.

The idea that it is possible to obtain a perfect account of nature underlies the development of modern science. Immanuel Kant's philosophy of science can be seen as the first modern attempt to articulate this idea. Though Kant cannot be seen as a discoverist thinker, he believed that the laws of natural science are indubitably correct because they are based on the a priori categories of cognition, which are applied to phenomena and to which phenomena conform perfectly. Clearly, the significant successes obtained by classical mechanics through the centuries strongly supported the conviction that the correct representation of the universe had been obtained and that science had reached the final truth.

The Crisis of Classical Mechanics and the Problem of Induction

The crisis of such a solid theory as classical mechanics undermined the key assumption on which the discoverist position rests: It undermined the idea that, on the basis of observation, it is possible to derive models that coincide with reality. The inadequacy of classical mechanics suggested that models are, at best, approximations of reality and that they remain ontologically distinct from it.

The crisis of classical mechanics revived one of the most controversial issues in epistemology: The Humean problem of induction according to which no matter how much evidence is accumulated in favor of a theory, the theory can be, at any moment, disconfirmed by further observations. The reemergence of the issues raised by Hume is testified by the fact that a significant number of critical works on induction are coeval to the crisis of the Newtonian paradigm.

In the early twentieth century, Henri Poincaré (1902) argued that scientific theories are not inductive generalizations of experience but are *conventions* that science uses because they yield to useful predictions. Just few years later, Pierre Duhem (1906) criticized Newton's contention that the theory of the universal gravitation was obtained by observation and generalized by induction. Through the well-known example of the "inductivist chicken," Bertrand Russell (1957) stressed the idea that the principle of induction cannot be either proved or disproved on the basis of experience and that it should be accepted as an a priori principle. Karl Popper (1935) firmly rejected the idea that science is characterized by the use of inductive methods. According to Popper, scientific theories are bold speculations that are not obtained by induction from experience nor are definitively verified by it. Following Kant, Popper held that scientists do not draw scientific laws from nature, but they rather apply them to nature. Yet, Popper opposed Kant's view that scientists must necessarily succeed in applying scientific laws to nature, and he insisted on the idea that scientific theories have a temporary status and that they are kept as long as they resist to the test of experience. Thomas Kuhn (1962) questioned, in his turn, the idea that science grows linearly by accumulating truths about nature, and he portrayed science as a process composed of irreconcilable steps. According to Kuhn, science is made of stipulations that the scientific community decides by agreement to use and eventually to replace with alternative ones, which typically lead to an innovative and often incompatible account of reality.

The Inventionist Position

The critical concerns raised in the twentieth century about the discoverist conception of science can be conveniently gathered under the above-mentioned heading of inventionism. Notwithstanding none of the thinkers mentioned in the preceding section, except Popper, explicitly uses the term *invention* to characterize the nature of scientific models, these thinkers share the idea that observation does not directly lead to theories and that it cannot be used to finally prove that theories correspond truly to reality.

Popper delineates the core idea of the inventionist epistemology through the thesis of the asymmetry between verification and falsification. With this thesis, Popper subverts the inductivist presumption that there is a positive relation between observation and theory: He puts forward the idea that the relation is rather in the *negative*. Though scientific theories can never be definitively verified by empirical observation, they can be definitively falsified by it. Coherently, Popper characterizes scientific theories as inventions of the human mind rather than as discoveries of the ontological properties of nature. It should be noted that, in this respect, the title "The Logic of Scientific Discovery" of the English translation of the original German "Logic der Forschung" appears contradictory and seems to suggest the opposite idea. Yet, at a closer look, there is no contradiction between Popper's inventionist view and the original title of the book as *Forschung* means literally *research* rather than *discovery*.

By delineating a composite inventionist and falsificationist conception of science, Popper aimed at forsaking the then mainstream logical positivist stance according to which *verifiability* is what distinguishes science from metaphysics. Popper's argumentation is that, since scientific statements cannot be definitively verified by induction from experience, verifiability cannot be used as a solid criterion to demarcate science from metaphysics. Popper found in the possibility of being tested, and potentially falsified by experience, the appropriate criterion of demarcation between scientific and metaphysical statements. Following Poincaré (1902), Popper considered the *predictive adequacy*, rather than the *ontological adequacy*, as the criterion to be used to justify a scientific theory. The predictive adequacy can be assessed on the basis of empirical tests and therefore pertains to science. On the contrary, assessing the ontological adequacy or, in other terms, the adherence to reality goes beyond the limits of the empirical method and therefore concerns metaphysics. A contemporary formulation of the idea that science should limit itself to what can be empirically assessed is Van Fraassen's *constructive empiricism* (1980). Constructive empiricism rests upon the assumption that the goal of science is to obtain theories that are empirically adequate and not to discover the truth about the unobservable aspects of nature.

By drawing a clear line of demarcation between science and metaphysics, Popper wished to preclude metaphysics from playing a role in the justification of empirical theories. Yet, Popper admitted that some speculative ideas, and he cited the example of ancient Greek atomism, had been of value for science as they have been subsequently turned into scientific theories. In acknowledging the value of metaphysics, Popper echoed Whitehead's idea that modern science owes much to metaphysics. As stressed by Whitehead (1926), science eventually rests upon the faith into the deterministic order of nature that should be seen as the reinterpretation of the medieval belief in a rational God. In particular, it can be noticed that classical mechanics relies upon the idea of an "intelligent and powerful Being" that is ultimately responsible of the order of nature (Newton 1713). Further, it can be observed that Leibnizian mechanics supposes that the world that an observer experiences is nothing but the one that God chooses as the best among many possible others (Leibniz 1710). Through the *principle of least action*, this idea carries on to the Euler-Lagrange theory, to the Hamilton-Jacobi theory, and ultimately to all contemporary formulations of classical mechanics (Lanczos 1986). Nevertheless, as far as Popper reasoning is concerned, the idea is that scientific theories should be justified only on the basis of their predictive ability. As explicitly argued by Popper (1963), metaphysical assumptions, like the one of the perfect adherence to reality, can drive scientists toward interesting research directions. Yet, the theories that are devised along these research directions are to be regarded as conjectures that can be justified only on the basis of the fact that they lead to reliable predictions.

By arguing that science does not rest upon truths derived by induction from experience but rather on bold conjectures that precede observation and that are then checked against it, Popper claimed that he had skipped the problem of induction. Yet, by emphasizing the inventionist character of science, Popper raised a central epistemological issue: the *objectivity* of science. Indeed, stating that science invents laws *about nature* and does not discover laws *in nature* amounts to abandon the idea that scientific knowledge is obtained from, and justified on the basis of the observation of, a reality that exists independently from our mental representations. Popper (1935) provided an answer to this issue by introducing the idea of the *intersubjectivity* of science: Though scientific theories are inventions, they are not arbitrary because the predictions derived from them are "intersubjectively tested" by the scientific community according to well-defined experimental protocols.

The very idea that science is about prediction rather than about the discovery of final truths traces back to concerns raised in the late nineteenth century. This idea is paramount to Mach's epistemology. Before the crisis of classical mechanics, Mach (1883) developed an *instrumentalist* conception of science according to which scientific theories have not to be intended as referring to real entities. According to Mach, scientific theories are rather useful instruments for making predictions. Mach's epistemology, in its turn, may be traced back (Popper 1953) to the one of Berkeley (1710). With his composite empiricist-instrumentalist position, Berkeley anticipated Mach in delineating the idea that scientific theories are justified by their practical utility and in denying that science can discover the intimate nature of reality.

The instrumentalist view of science remained marginal until the end of the nineteenth century. It became mainstream in the early twentieth century, as it appeared the adequate epistemological background for the then-newborn paradigms of relativistic and quantum mechanics. The discussion that confronted Niels Bohr (1949) to Albert Einstein on the interpretation of quantum mechanics shows that the Berkeleian and Machian views of science deeply influenced the epochal turning point that characterizes physics in the twentieth century. Although Einstein is typically presented as an advocate of a realist interpretation of the quantum theory, he agreed with the inventionist thinkers that scientists do not draw from observation theories that correspond perfectly to reality. As put by Einstein (1949), reality "is mentally constructed," and the constructs that are used by scientists to account for the sensory experiences must not be regarded, as Kant did, "as unalterable (conditioned by the nature of understanding) but as (in the logical sense) free conventions": These conventions are justified by their ability to provide a "logical representation" of sensory experiences.

Contemporary Incarnations of the Discoverist Position and the Current Debate

Notwithstanding the idea that science is about discovering the truth has undergone serious criticisms in the first half of the twentieth century, starting from the 1960s, a discoverist stream of thinking reemerged in the literature. This stream of thinking goes under the name of *scientific realism* (Smart 1963; Boyd 1973; Putnam 1975). This new version of the discoverist view revised significantly the notion of truth. Notwithstanding it considers truth as the final goal of science, it acknowledges that science cannot deliver absolute truths. This fundamental change of view emerged from the fact that the notion of truth was replaced by the notion of *truthlikeness* (Oddie 1986; Niiniluoto 1987). The idea behind this revised notion of truth is that science does not state absolute truths but only approximates truths by eliminating false theories and by devising more accurate descriptions of reality.

The notion of truthlikeness is formulated and analyzed within the *similarity approach* (Oddie 1986; Niiniluoto 1987) where it is adopted to provide an explanation of the predictive success of scientific theories. Scientific realists acknowledge, in line with the inventionist view, that scientific theories are selected on the basis of their predictive success. Yet, they claim that it is necessary to recur to the notion of truthlikeness in order to both decide which theory to select among competing ones that are equally predictively successful and to explain why the selected theory is more successful than its rivals: Through the so-called *no miracle argument* (Putnam 1975), a number of realist thinkers argued that the amazing success of science would be miraculous if scientific theories were not, at least approximately, true of the world.

The scientific realist strategy to move from an absolute to a softened conception of truth is motivated by the need to respond to the issue of falsification. Yet, accepting that science is about approximating truth rather than discovering it constitutes a breakthrough in the scientific realist epistemology. It heads the realist epistemology toward an *asymptotic discoverist* conception of truth. This asymptotic conception amounts to renounce the key realist assumption that scientific theories correspond to reality. It nonetheless implies the hope that eventually, and possibly in infinite time, theories converge to truth.

The realist attempt to revive the notion of truth has been seriously challenged in the 1980s by Larry Laudan (1981). Laudan questioned the very idea that the predictive success of a theory is an indication of the fact that the theory is a true account of reality. Laudan pointed out that the history of science indicates that the empirical success of scientific theories does not guarantee either their genuine reference to reality or their truthlikeness. Classical mechanics is a representative example in this sense. Recently, it has been argued that the reasons why the notion of truthlikeness has been perceived as unsatisfactory are related to the double role that this notion plays in the similarity approach: Using Kant terminology, Piscopo and Birattari (2010) clarified that the dissatisfaction derives from the fact that the notion of truthlikeness plays a *constitutive role* in the selection of empirical theories while it should play only a *regulative role* in their conception. Within the similarity approach, truthlikeness performs, on the one hand, the regulative function of a stimulus to continuously search for a more complete account of reality. On the other hand, it plays a regulative role while deciding which theory to select among competing ones: The conclusive criterion for preferring a theory to a rival one is the better correspondence to reality.

The problematic issue with the regulative use of the notion of truthlikeness is that the crisis of classical mechanics has definitively ruled out the idea that a scientific theory can be shown to truly correspond to reality. It is therefore hard to see how the criterion of truthlikeness can act as a regulative principle for the selection and the justification of scientific theories.

Notwithstanding the challenge posed by the crisis of classical mechanics to the idea that science is about discovering the truth, there is nowadays a propension in epistemology toward a discoverist position as it is testified by the reemergence of realist perspectives. This propension has a deep motivation. It should be seen as an attempt to preserve the objectivity of science: It is aimed at defending the idea that there is a reality independent from the observer and that this reality can eventually be discovered through observation.

At a closer look, the tension between the discoverist and the inventionist views of science is not a prerogative of epistemology. This tension emerges, for instance, clearly in the artificial intelligence and machine learning field that goes under the name of *knowledge discovery in databases*. As its name suggests, the field of knowledge discovery in databases rests upon the idea that it is possible to build programs that can discover general laws from data sets. The expert system BACON.1 (Langley et al. 1987) is a milestone in machine learning and should be regarded as a realization of the inductivist and discoverist idea. As it is made clear by its name, the assumption behind the implementation of BACON.1 is that this system is built to *extract* theories *from* nature rather to *construct* theories *about* nature. In other words, the very assumption that is made is that since BACON.1 does not devise theories but discovers them in nature, these theories are necessarily a true representation of nature itself.

It must be noted, yet, that though the discoverist view has pervaded the machine learning field for decades, some sectors of the community seem to have eventually switched to an inventionist position. In particular, nonparametric statistical methods such as bootstrap (Efron and Tibshirani 1993) and cross-validation (Stone 1974) do not rest on the hypothesis that the real system under observation belongs to the model space: If the system does not belong to the model space, the learned model cannot coincide with the system itself, and therefore, no discovery is possible. In such a case, the learned model can be at best an approximation of the system. The learned model can be therefore considered only as a useful invention.

Concerning the possibility of building inductive machines, just few years before BACON.1 was built, Popper raised doubts about the idea that a machine could discover scientific laws by induction from simple observation:

> [...] *we may consider the idea of building an inductive machine. Placed in a "simplified world" (for example, one of sequences of coloured counters), such a machine may through repetition "learn", or even formulate, laws of succession which hold in "its" world. If such a machine can be constructed (and I have no doubt that it can) then, it might be argued, my theory* [here Popper means the theory that science does not rely on induction] *must be wrong; for if a machine is capable of performing inductions on the basis of repetition, there can be no logical reasons preventing us from doing the same. The argument sounds convincing, but it is mistaken. In constructing an induction machines we, the architects of the machine, must decide* a priori *what constitutes its "world"; what things are to be taken as similar or equal; and what* kind *of "laws" we wish the machine to "discover" in "its" world. In other words we must build into the machine a framework determining what is relevant or interesting in its world: the machine will have its "inborn" selection principles. The problems of similarity will have been solved for it by its makers who thus have interpreted the "world" for the machine*. (Popper 1963)

Conclusions and Future Directions

A tension between the *discoverist* and the *inventionist* views can be seen both in science and in epistemology. The discoverist view is motivated by the need to preserve the objectivity of science, but this view has to deal with the problem of induction. The inventionist view skips the problem of induction, but it has to renounce the idea that scientific knowledge has an objective character.

The tension between the discoverist and the inventionist views appears unavoidable in future discussions about the nature of science. On the one hand, the discoverist view responds to the philosophical concern of ensuring that science is not an artifice but a rational and objective enterprise. On the other hand, the inventionist view is enforced by the pragmatic acknowledgement that even the best confirmed theories are simply conjectures that can be eventually abandoned and substituted by alternative ones that are expected, in their turn, to face the same destiny as their predecessors.

Further research is needed in order to solve the above-mentioned tension. Popper's falsificationist view and the related conception that science does not produce truths but rather builds intersubjectively testable theories appears to be a viable solution: Falsificationism describes scientific theories as not arbitrary though it accounts for their fallible character.

Cross-References

- ▶ Convergent Versus Divergent Thinking
- ▶ Creativity and Innovation: What Is the Difference?
- ▶ Ideas and Ideation
- ▶ Imagination

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Inventive Creativity

► Creative Mind: Myths and Facts

Inventive Problem Solving (TRIZ), Theory

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Synonyms

Systematic innovation

Introduction

How people invent? Famous scientists and engineers sharing their memories, as well as psychologists studying the creativity process, describe similar situations: An individual facing a difficult problem is mentally exploring various approaches, persistently trying and rejecting ideas until the right one comes. Psychologists call this process trial-and-error method (T&EM).

T&EM has a great history. It was used to create first stone knives, bows, guns, windmills, building, ships, and almost everything we can see around. Some results are astonishing: Polynesian catamarans, old Chinese, Norwegian, or Russian boats are practically perfect. Each element has the best shape. However, archeological research has shown that even 500 years ago, these vessels were rather far from perfect. One hundred years after another of repeating practically the same shapes, the builders yet were introducing slight changes into design. Some of them were