

***Discovery in the Physical Sciences.* Richard J. Blackwell. Notre Dame IN: University of Notre Dame Press, 1969.**

Preface:

Twentieth century expansion of scientific knowledge is attended by *conceptual upheavals* in man's view of self and world.

This is paralleled by increased interest in the philosophy of science, though little attention has been given to the act of discovery – perhaps because insight/genius is unique and difficult to analyze.

This book attempts to *begin* such analysis. It does so in three divisions:

1. Chapters 1-3: reformulation of the problematic.
2. Chapters 4-6: theory of discovery from epistemological point of view.
3. Chapter 7: ontological status of scientific objects.

Chapter ONE: An Additional Program for the Philosophy of Science

The common approach is analysis of science as a body of knowledge, in terms of logical structure of explanation/prediction/verification.

Such philosophers (e.g., Popper) admit the reality of discovery but deny that it can be analyzed for any structure; some go so far as to term it irrational, and thus utterly unexplainable.

Three thinkers make contrary indications:

1. Hanson: reasons which (a) suggest a hypothesis are basically different from (b) those which lead to accepting hypothesis.
(a) Has a 'logic' irreducible to (b).
2. Kuhn: There is a repeated pattern in scientific revolutions.
3. Koestler: analysis of the "bisociative act".

Thus: the claim is that a *reasonable account* can be given of "discovery" (even if it should not be called a "logic").

Basic question at issue: "What is the nature (task/scope/method) of the philosophy of science?" – How this is answered will determine one's openness/closedness to analysis of discovery.

Preliminary statement of the problem:

There is *no mechanical method* of discovery (i.e., no automatic process of transition from data to hypotheses).

1. Analysis of formulated scientific system does much to explain science; but this presumes the presence of previously structured science.
2. Historical/sociological/psychological factors are significant.

But these two factors are not exhaustive of all that is involved in the origin of new hypotheses.

“Logic of discovery” = an *intelligible account of the origin of hypotheses* in terms other than those of the formal patterns of thought and language.

Question: Is there a middle ground requiring an intelligible account between (a) the hypothetico-deductive structure (HD) of completed science and (b) sociological/psychological motivations of the scientist?

The question forces us to examine science as it has been developed; it cannot be answered a priori.

Descartes/Newton on the Principle of Inertia

The “laws” of Descartes and Newton are similar:

- At the level of *factual* meaning, they are virtually identical: a body of itself tends to remain unchanged in its present state.

Note that both are talking about idealized states of affairs.

- As to *theoretical* meaning (why?), Descartes and Newton diverge:
 - Newton introduces his concept of *mass*: thus, the principle of explanation is located *within the body* itself.

[Effects of mass = (a) weight and (b) resistance to change.]

- Descartes: immutability of God (“divine conservation”) means that the overall amount of matter/energy in the universe *must* be constant.

Thus, Descartes asserted that the universe was not a self-intelligible system; therefore, his principle of explanation was *external*.

Note also that Descartes’ a priori notions were important in leading to the discovery of various laws of conservation in physics.

The question involved the concept of quantity of motion; i.e., given a particular case of physical change, how much motion is present? (This involves many questions as to relevant factors, etc.)

Descartes: some quantity of motion is continually preserved in the universe.

He *presupposes* that he has determined the *relevant* factors and their interrelationships: volume/scalar-velocity.

Some *choice had to be made*.

Newton advances over Descartes in selection of mass (contra volume) and of velocity as vector (contra scalar).

Note: The selection and interrelation of pertinent factors were essential steps in discovering the theory. Some selection was needed!

Some components of the Act of Discovery

[We cannot generalize too much from one case, but perhaps we can learn something.]

1. A process of *selection*: one can't deal with everything at once; truly relevant factors must be selected.

Note: the fact that Newton's law of impact was *verified* and that Descartes' was not does not explain *how they arrived* at them.

The commitments of selection from general limitations within which an hypothesis can be generated.

2. *Interrelationship* of these factors must be grasped in order to hypotheses to be formed.
3. Process of *idealization*: abstraction from concrete particulars.
4. New hypothesis must be capable of *integration* within the over-all structure of a science.

This integral unity exerts influence on the formation of new hypothesis.

5. *Epistemological commitments* are involved.

E.g., Descartes and Newton are 'worlds apart' on their position concerning the possibility of an inductively based physical science.

Epistemological *expectations* guide thought and theorizing.

6. *Openness* to changes of meaning in the basic concepts of science.

The meaning of basic terms change: e.g., Descartes' and Newton's "conservation".

"Transformation".

Possibility of a Theory of Discovery

The study of these factors is an investigation of different from (a) study of science as finished product, and (b) sociological/psychological conditions.

Science begins with empirical data – the transition from data to hypotheses is the first phase of science and the locus of the act of discovery.

Data → Hypotheses → Prediction → Verification → Falsification

The six factors delineated above pertain here: data → hypothesis

The investigation of this transition involves "epistemological" issues.

The philosopher of science takes science as a given fact and tries to uncover those elements which are needed to understand it.

It must always be remembered that the advance of science is a mysterious process.

Chapter TWO: Types of Discovery

Some discoveries are of “things” (physical realities) hitherto unknown; but discoveries of “laws/theories” are not of “things out there”.

“Discovery” also connotes *approval*; it must become part of the accepted body of reliable scientific knowledge (i.e., novelty in itself is not sufficient); it must be of “relatively permanent value”.

Thus, “discovery” is a somewhat *relative* designation because changes in science lead to reevaluation.

Discovering THAT and Discovering WHY

E.g., Copernicus (1473-1543) made an *interpretive*, not observational, discovery.

Involved was an improved understanding of old data, not new data; an entirely new *perspective* is discovered.

Copernicus offered little factual evidence; his theory simplified some problems, but because he clung to Aristotelian notions of circularity new complications also arose.

Galileo (1564-1642) discovered that Venus revolves around the sun, and by *analogy* was convinced of the Copernican system concerning earth.

Tycho Brahe had made a number of *factual* discoveries; e.g.:

- o Exploding star Cassiopeia (1572);
- o Comet cutting through paths of planets (1577).

Tycho also presented an interpretive theory of astronomy, later shown to be incorrect and thus forgotten.

“Interpretive ‘discoveries’” are extremely *complex* conceptually; they have ramifications for the entire conceptual framework.

E.g., Tycho insisted on geocentrism for theological reasons.

Science has always resisted abandoning its current conceptual scheme.

Discovering why something is the case requires integration into the over-all structure of human knowledge and thus is highly complex.

Example: Kepler (1571-1630) discovered things *about* the ways in which the planets move; Newton (1642-1727) discovered *why*.

Fact and Interpretation-of-fact are closely interwoven.

Both are necessary; but one may be more prominent than the other in a given act of discovery.

Note: It has been discovered that the half-life of radium is 1620 years; we do not yet know why.

Discovering-why presupposes discovering-that; both are discovery.

Correlation with the Hypothetico-Deductive Account

H-D is standard scientific method.

Explanation consists of two types of statement:

1. *Explanandum*: descriptive sentence of phenomenon requiring an explanation.
2. *Explanans*: set of sentences providing the sought explanation.

This account deals with *already formulated* scientific knowledge.

Explanation consists in the relation of deductive derivability of the *explanandum* from the *explanans*.

There are four conditions:

1. *Explanandum* must be logical consequence of *explanans*.
2. *Explanans* must contain at least one general law which is actually needed for the derivability of *explanandum* from *explanans*.
3. *Explanans* must have empirical content.
4. Statements in the *explanans* must be true.

H-D account is restricted to *sentences* describing physical phenomena; it is an attempt to formulate an understanding of the structure of scientific explanation; it thus presupposes the availability of the statements that comprise the *explanans* and the *explanandum*; this is an examination of the structure of science *after the fact*.

But the question can be raised: Where do the *explanandum* and *explanans* come from? Though this question cannot be raised in the H-D account itself.

Note: a consideration of the process of discovery, as distinct from the logical structure of explanation, bears directly on the question of the origins of scientific knowledge.

Discovery: How do *explanandum* and *explanans* originate?

Explanation: What are logical relationships between *explanandum* and *explanans*?

In explanation, analysis is brought to bear only on the logical patterns of deduction embodied in the finished product.

Approaches to science through (a) the H-D account and through (b) analysis of the process of discovery are *supplementary*; neither is sufficient alone.

Together they enable us to examine both the genesis of *explanandum/explanans* and their logical relationships.

Note: *Explanandum* = "discovering that" *plus awareness of the need for explanation*.

This is important because the mind can rest content simply with knowing that something in fact is the case.

There must be a further sense of "incompleteness".

Note, also: the distinction between empirical and theoretical knowledge:

- *Empirical*: Statements expressing the relations between observable entities and events which are arrived at by inductive procedures.
- *Theoretical*: Statements expressing the relations between non-observable entities and events which are produced by mental creativity.

This distinction parallels that between discovery-that and discovery-why, but not exactly, for it is not clear how “observable” should be defined (this would depend on an articulated theory of sense experience).

Analysis of the types of discovery moves from the plans of sensory experience toward the formation of generalized scientific principles.

Routine Discovery and Revolutionary Discovery

E.g., in beta-ray decay of nucleus, there was an unaccounted for loss of energy; rather than reject accepted general physical theories, the existence of neutrinos was postulated in 1934 – the existence of neutrinos was verified in 1956.

This (1956) is an example of discovery made within the confines of previously established scientific knowledge.

Extension-of/addition-to established conceptual framework is routine discovery.

Another example was the discovery of the planet Neptune.

In other cases there is a radical change.

E.g., quantum theory necessitated a fundamental break from classical electromagnetic theory (Planck).

Totally new foundations were needed; there was a deliberate break from earlier views.

This had notable impact on concepts of: space, time, simultaneity, mass and gravitation.

Such discoveries are revolutionary, but they do not occur in isolation – both the old and the new regimes must be understood in their interactions upon each other.

Routine discovery can involve deductive application of established principles to new empirical evidence; or extension of an established set of principles to new areas of phenomena, not explicitly covered by original theory (e.g., mechanics to “conduct” of gases); or mathematical reformulation of a prior theory.

Routine discovery is the extension-of or addition-to a previously accepted conceptual framework.

Between routine and revolutionary discovery, there is a wide range of mixed cases; historically, both aspects must be carefully sorted out.

There are no 'rules' for deciding whether an anomaly calls for revolutionary revision or routine extension.

If a theory is fundamental and/or has a great deal of verification, revolutionary revision is unlikely.

And if a revision would involve introducing a number of assumptions, it is also unlikely.

Kuhn: scientific advancement is not simply additive.

Routine growth is continuous.

Revolutionary growth is discontinuous.

Discovering-that and discovering-why can both be either routine or revolutionary.

Accidental Discovery (especially in biological/medical sciences):

This refers to discovering-that. The accident lies in fortuitous events which produced conditions for observation, but the discoverer comes to the situation well prepared to see its significance.

Frequently, he has been struggling with a problem for a long time.

E.g., Goodyear: he was *prepared* for the act of insight.

This calls attention to the *centrality of the act of insight*.

Chapter THREE: Four Levels of Explanation

How does one *explain*? Various ways of attempting to provide a *reason why something is the case* are possible.

Some attempt to assert that all scientific explanation is deductive.

But deduction is a process, not content – and explanation revolves around *meaning*.

Complex phenomena (such as the act of discovery) admit of several types of explanation – several levels, and different aspects of the act will require different kinds of explanation.

Logical Approach

Hanson argues that discovery has a unique logical structure that is distinguishable from the logic of the H-D system.

He analyzes Kepler's work and concludes that the thought processes leading to suggested hypotheses are different from the process of verification.

- Hypotheses: suggested by, e.g., analogy, symmetry, authority.
- Verification: appeal to empirical evidence.

H-D fails to ask where hypothesis comes from, and that is precisely the exciting and original point in science – That is where the 'logic' of discovery lies (transition from data to hypothesis).

Hanson defines “Hypothesis” as: a general statement of explanatory power – such explanation is not the result of mere enumeration.

However, to discover empirical regularity can be a genuine discovery-that – Hanson’s denial of an inductive logic of discovery applies to discovery-why.

But what is meant by “logic”? This at least means that it is not merely a matter of mental process (psychological) but gets at the meaning-content of the issue at hand.

A distinction may help arrive at clarity:

- a. *Rule*-centered inference: bears on formal structure of propositions.
- b. *Content*-centered inference: based primarily on meaning content.

The distinction between reasons suggesting hypothesis and those verifying hypotheses state a content-centered inference.

Routine discoveries are largely explainable in terms of rule-centered inference; in revolutionary discovery, the thought process bears on the meaning content of the concepts.

Question: Can a content-centered theory of revolutionary discovery be worked out?

Content-centered inferences are central in the transition from data to hypothesis; this is where the crucial work of science occurs.

Psychological Approach

Empirical psychology has so far been unable to explain the act of discovery.

Koestler has done extensive analysis (introspective) of the personal experience of discovering.

Bisociation: recognition of similarities between two previously unrelated matrices of thought.

This view emphasizes that discovery is less a process of uncovering new facts, than of seeing old data in new relations/perspectives.

Bisociation is a two-phase process:

1. *Breaking away* from established patterns of thought and the limited range of permissible associations.
2. Establishment of *new associations* through recognition of similarities of previously unrelated elements.

The *unconscious* plays a significant role in bisociation: freer play of associations, where pictorial images open a wide range of visual bisociations which are normally excluded by linguistic structures.

But in the absence of any widely accepted theory of the unconscious, this still lacks clarity.

Historical Approach

Does analysis of history of science reveal *repeated patterns*? Kuhn insists that it does.

“*Paradigm*”: a conceptual system which is sufficiently powerful to overcome prior competing schools of thought and sufficiently open-ended to generate many routine problems for solution by the scientific community.

Pattern:

- ◆ Paradigm is given.
- ◆ Routine problem-solving within paradigm
- ◆ Anomalies arise and exert pressures against paradigm.
- ◆ Crisis forces fundamental reconsideration: theorizing.
- ◆ Act of discovery.
- ◆ Reversion to routine problem-solving.

Kuhn thus posits discovery as a gradual/structured process.

Epistemological Approach

Concerning meaning-content, examination the different types of knowledge present (a) before and (b) after discovery is necessary.

“After-knowledge” involves a *statement of generality and necessity* not present before.

Frequently this involves the introduction of non-observable entities.

- How?
- What does this reveal about discovery?

General epistemological question: how are transitions made in knowing? Twentieth century epistemologies of science have generally neglected the act of discovery for two reasons:

1. The linguistic/analytic bent of contemporary philosophy limits consideration to already articulated scientific results.
2. David *Hume's* (1711-1776) influential epistemology leaves no room for a real act of discovery; for him, all sense-impressions lack relations, and thus the mind constructs relations (not ‘discovers’).

Since interrelatedness is essential to meaning/understanding, isolated facts are opaque to human knowing.

However, Hume’s epistemology is untrue to human experience; our direct experience is of intricately interrelated objects and events – but Hume’s *mechanistic reductionism* remains influential.

Blackwell insists on granting that there is structure and *relatedness pre-given in things*, but acknowledges that discovery is not simply a matter of ‘uncovering’ these.

Epistemologically, discovery is the *interplay between* (a) *grasping the pre-given patterns in nature*, and (b) the *mind transforming* and refashioning.

“Discovery” is the meeting ground of these two forces; both must be present.

Epistemological distinctions will bear on which force is emphasized: (a) empirical content or (b) mental creativity.

Scientific laws/theories reveal significant *transformations* of content:

1. Selection: mind limits attention to relevant factors.
2. Idealization: 'physical' transformed into non-physical entities.
3. How can analogies give us knowledge?

These raise *questions*! And thus further consideration is needed before we know if we can have an epistemology of science. It becomes obvious that this will be very complex, given the various combinations of (1) types of discovery and (b) types of explanation.

<u>-a-</u>	<u>-b-</u>
That	Logical
Why	Psychological
Routine	Historical
Revolutionary	Epistemological
Accidental	

Synthesis of Preceding Material

There are two phases of scientific thought:

- Originative = content-centered.
- Verification = rule centered.

The first phase is the locus of discovery: focus is on meaning-content.

Discovery can be analyzed, but not in terms of a nest and systematic pattern; it more often than not occurs in a *fragmented process*.

In individual discoveries, there are elements of spontaneity and uniqueness, but there are also *relatively common patterns*. Examination of these may allow us to arrive at partial explanations; it will not be possible to arrive at a single theory to explain all discovery, since there are many kinds of "discovery" (which is a rather generic term).

Revolutionary discoveries will be the most enlightening; routine discoveries coalesce largely with the H-D account.

Kuhn's historical and Koestler's psychological contributions seem to indicate that the various levels of explanation can support the emergence of a higher synthesis.

But given the broadness of the historical approach, the psychological and epistemological seem most fruitful.

Blackwell's focus is epistemological: What is the nature of the epistemology involved in the initial discovery of scientific laws and theories?

Since discovery is not a mechanical process, the integral unity of the act of discovery must be kept foremost in mind; components must be seen in their interrelatedness, not in isolation: "Conceptual gestaltism".

Chapter FOUR: The Adaptation Theory of Discovery

Philosophy begins in wonderment and is rooted in bewilderment.

The beginning point of epistemology is the attunement between (a) the human mind and (b) physical nature.

- ◆ Materialism: mind reduced to nature.
- ◆ Idealism: nature reduced to mind.

The question of this attunement is not an abstract one; the very possibility of science is based on assuming this attunement.

The act of discovery is located at the point of *conjunction between these two realms*; an epistemology of discovery begins by questioning the "how" of this conjunction.

Francis Bacon (1561-1626) distinguished two erroneous views of scientific knowledge:

- 'Ants' merely record facts (extreme empiricism).
- 'Spiders': all interactions come purely from within (extreme rationalism).

Both of these forces contribute to science: pre-established dictates of nature merge with the interpretive/adaptive functions of mind.

It is possible to hold these erroneous views concerning discovery:

- 'Ants': Discovery is merely finding what is 'out there' to be found.
But this misses many aspects: How do I know what to look for? How do I recognize that I've found something? Etc.
- 'Spiders': Discovery is purely constructionist with the mind creating what is found.
But this also misses many aspects: If a concept does not bear any physical meaning, it is a mere calculational convenience and not a part of physical science.

Each act of discovery is a joint act of these two components, with a variance of relative proportion and influence.

The 'ants' and 'spiders' have more in common than they usually realize: 'ant' denies that there are structures in nature; 'spider' claims to create structures, as there are no real structures.

Thus: empiricism and rationalism appear as two sides of the same counterfeit coin.

Needed is a 'bee' analogy: a middle course receiving previously structured meaning-content from the physical world, yet actively refashioning and integrating that content.

The act of discovery is the primary focus of the interplay between these components.

The Mind-Nature Confrontation

The epistemological task is overcoming empiricism and rationalism, while preserving the values of each; thus facing the complex task of explaining how science arises from the merging of the dictates of nature and the active/creative functions of mind.

Basic assumption: neither physical nature nor human mind have any meaning in isolation from each other.

- The physical world is a nature-existing-for-mind.
- Human intelligence is a mind-existing-for-nature.

Part of the reality of each is to be in essential relation to the other.

This is not to deny their distinctiveness (which would be monism); but it is to reject the radical Cartesian dualism of mind and matter.

Viable middle ground = mind and matter are distinctively different realities (*contra* materialism and idealism), but they are not self-contained, each having an *essential relation* to the other.

They are intrinsically relational, interdependent for meaning.

Analogy: in relativity theory, the reality and meaning of space and time are independent.

Their relatedness is internal, not superimposed; the relation enters into the very reality of mind and nature. To speak of mind-in-itself or nature-in-itself is an abstraction; it may be helpful to do this for analysis, but these abstractions must not be objectified for they are not given in the immediacy of human experience.

The epistemological question can be restated as follows: How are we to explain the wondrous harmony/attunement which exists between mind and nature?

Confusion has frequently arisen because of the degree of attention to the abstract entities in isolation.

Blackwell asks us to focus attention on the immediate context of human experience, which is the confrontation of mind and nature as internally related.

The discovery phase of science begins with concrete experience and, through reflection, moves to the formulation of hypotheses which then enter the verification phase.

The discovery phase involves the mutual influence of the dictates of nature and the creative functions of mind. The viable unity of these two forces is to be understood in light of the confrontation of mind and nature in a matrix of internal relatedness.

The epistemological question becomes: How is the primitive mind-nature confrontation at the base of human experience progressively *elaborated* and extended to the direction of the formulation of scientific hypotheses?

Adaptation refers to the *process of mutual adjustment between mind and nature*; the internal relatedness of these two forces is transformed from an initial condition of vagueness to more and more elaborated patterns of explicit relatedness.

Chapter FIVE: Adaptation as the Elaboration of Structures

The 'world' immediately presented to mind/imagination by nature is extraordinarily complex; initially mind is *overwhelmed*/bewildered – this complexity thus constitutes a barrier to human understanding.

Mind cannot grasp the whole of nature *ab initio*, and so begins with small segments by a process of *limitation*; this is the beginning of the process of adaptation.

Thus, nature dominates the initial confrontation with mind; but mind's ability to adapt is witnessed in the accelerated progress of science.

We must always remember, however, that scientific progress has always been slow/painful; only after the fact does it seem easy!

It is significant to note that this preliminary adaptation (limitation) of mind to the complexity of nature is the area where the real work of discovery occurs; *understanding the adaptations which prepare for the act of insight is the fundamental task of an epistemology of discovery*.

Thus it must be noted that an experienced scientist brings a great deal of conceptual background to the mind-nature confrontation.

This leads to a *dual complexity*: not only that of nature's dictates, but also that of the scientist's pre-established conceptual framework.

Elements of Elaboration

Premise: Mind and nature are mutually related and mutually adjust to each other in the genesis of human knowledge.

There are two basic forms of this adaptation: elaboration/transformation.

Elaboration = that adaptation of mind and nature which is *productive of physical meaning*.

Its beginning is in the amorphous mind-nature confrontation; accordingly, there are elements of elaboration (though these are not rigidly sequential).

Thus, elaboration is the delineation in specific items of the mind-nature confrontation; accordingly, there are elements of elaboration (though these are not rigidly sequential).

1. *Curiosity* as the Source of Inquiry.

Discovery occurs within a *problematic context*; thus, a problem is a necessary but not sufficient condition for the act of discovery. Curiosity/intellectual-concern is a further necessary condition.

A problem always arises out of a prior context of knowledge, as an anomaly within a context that is considered normal and regular.

Thus, the initial problems of science are highly indebted to common sense.

The very recognition and formulation of the problem places the mind in a special perspective: *which* problem is asked as a question and *how* it is asked are crucial *commitments* in inquiry.

This is where the mind makes its initial adaptations to the dictates of nature; and there is no guarantee that the right question will be asked and formulated properly.

Genius often consists in a fruitful posing of the problem.

2. The *Sorting-Out* Process.

Galileo's development beyond Aristotle's theory of motion was made possible by beginning with a different perspective toward nature; a shift in the problematic and therefore in the adaptation of mind to nature occurred.

The "sorting-out" process refers to *identifying the physical factors relevant* to formulating the problem.

Which factors are relevant, which are only accidentally relevant and may be disregarded, and which are essentially relevant to an understanding of the phenomenon under investigation?

Answering such questions constitutes a further step in the adaptation of mind to nature.

Identifying relevant physical factors among the dictates of nature further specifies the content of scientific knowledge and gives a more definite structure to the mind-nature confrontation.

This sorting-out process is neither mechanical nor automatic.

In nature, the process is abstractive; it may be termed a *selective abstraction* – nature in its full concreteness and complexity has been replaced by an abstractive/selective perspective on nature.

3. *Interrelating* Recognized Components of a Structure.

The primary object of the act of discovery is the interrelationship of the relevant physical factors.

Meaning is primarily a relational affair; discerning relationships is the crucial feature in many discoveries.

Again, there are no specific rules which will tell the investigator how to go about this task.

Grasping the relational structure completes the first level of scientific discovery; here the scientific elaboration of the mind-nature confrontation has reached a momentary resting point.

To this point there has been a continual interplay of (a) the formulation of the problematic, (b) the identification of relevant factors, and (c) the discernment of a relational structure, each reciprocally modifying the others as incomplete aspects of the unified process of discovery.

4. *Integration with Other Knowledge.*

Each discovery must take its place in the overall framework of science and in the entire context of human knowledge and culture. This involves complex further relations which add to the fullness of meaning of each concept.

Often, *further applications* of a concept come to be seen, far beyond the range of the original problematic.

A structure, once discovered, becomes an element in a complex conceptual whole, and its position in that context contributes significantly to the fullness of its meaning.

This integration is not only scientific, but also occurs with other branches of human knowledge.

5. *Transcending Actual Experience.*

There is a steady movement toward *generalization of meaning*; this is the process of transcending actual experience.

The generalized knowledge supposed to reside in scientific law extends far beyond the constricted base of actual experience.

The *omnispatial* and omnitemporal aspects of the meaning of discovered structures are introduced by an extension of the content of actual experience to further ranges beyond the actual evidence.

Such generalization is a provisional universal; it makes an assertion which is omnispatial and omnitemporal in import with the proviso that exceptions may arise.

The generalization is asserted as a genuinely universal statement in the absence of any known exceptions, although the scientist is *open* to the possibility of modification as his actual experience is extended.

As such, the scientist has (a) transcended actual experience in his generalization and yet (b) simultaneously recognizes the role of further actual experience as corrective.

The repeated dictates of nature reveal a *pattern of regularity* which is an essential part of the structures discovered in science.

That is, there is overwhelming evidence of the spatial/temporal conformity of discovered structures.

It is this which justifies the transcending of actual experience.

What the scientist does is to extend the conditions and content of actual experience to further ranges of space and time.

The actually experienced conformity of discovered structures in instances which are separated by time and space makes this extension reasonable.

The Doctrine of Structures

Each of these steps permeate the others as complementary aspects of a unified whole – they are not temporally distinct steps.

Though the final insight occurs in an instant, it has been preceded by a lengthy preparation.

“Structure” = the *articulated relatedness of the elements of human experience produced by progressive specification of the mind-nature confrontation*.

“Structure” is that which is grasped by the act of discovery and subsequently serves as the proper object of scientific knowledge.

A “structure” constitutes the physical meaning-content of scientific understanding; it is what is asserted of nature by the mind.

The result of the mind-nature confrontation is a *system of relations* among the components of experience which is actually, and not merely potentially, articulated.

The dictates of nature are given in relatedness both among themselves and to the functions of mind.

The functions of mind are given in relatedness both among themselves and to the dictates of nature.

The concrete context of human knowing is the organic unity of mind and nature in interaction. The elaboration of this interaction/confrontation is the elaboration of a structure.

Discovery is first the grasping of a progressively elaborated structure.

Once a structure is discovered, it:

1. Serves as the proper object of scientific knowledge as it provides understanding.

2. Reciprocally reverberates on the meaning-content of other structures to which it is related.
3. Suggests further problems for the continuation of inquiry.

Such a structure has a mental and a physical pole:

- It is a *judgment* relating a series of concepts.
- It is a *physical fact*.

A structure is an articulation of the mind-nature relatedness and is both a concept and a physical fact, depending on which aspect of this relation is being emphasized.

Elaboration and 'Discovering-That'

The elaboration of an articulated structure is equal to 'discovering-that- such-and-such is the case.

Discoveries resulting from the elaboration of structures are discoveries of empirical *laws*, rather than theories.

Such discoveries may be either routine or revolutionary.

Chapter SIX: Adaptation as the Transformation of Structures

The overall growth of a science results in a cascading network of interrelated structures, with the overall network itself emerging as a special kind of logical structure.

That is, scientific knowledge becomes *systematized*; discovered structures become explainable in terms of their position in the system.

"Fact" = a structure discovered in the process of elaboration.

"Interpretation of fact" = an explanation arising from the deductive logical patterns of the system in which the discovered structure is placed.

There are two major difficulties in this systematization of scientific knowledge:

1. As science grows, the number of discovered structures tends to become unmanageable.
2. The effort to systematize is threatened by the appearance of anomalies at the level of discovered structures.

This is especially true in cases of a revolutionary discovery-that.

The structures discovered at the level of elaboration can and do give rise to a different kind of problem at the level of systematization.

How are the discovered structures to be interpreted?

What higher synthesis is called for as the mind attempts to become adapted more adequately to nature?

This situation is the occasion for discovery at the level of interpretation; this is the arena of creative theorizing.

Transformation vs. Elaboration

Since an elaborated structure is an understandable unit of meaning in its own right, the mind may come to rest satisfied in the understanding of such structures.

But a *further question* remains: *Why* the physical state of affairs expressed in a structure obtains.

To ask this question is to convert a discovered structure into an *explanandum*.

Thus, the first step in the process is to *recognize* that a physical state of affairs stands *in need of an explanation*.

Considerable insight is often required for this recognition and for the proper formulation of the interpretive question.

The precise manner in which the *explanandum* is *formulated* permeates the subsequent search for theoretical explanation.

What is called for here is the systematization of scientific knowledge in such a way that explanations can be provided by means of the deductive relations between an *explanans* and an *explanandum*.

“*Transformation*” is the type of mind-nature adaptation which is the process of the development of theoretical meaning.

“*Theory*” is a deductively organized system of explanation in which the *explanandum* is a structure previously discovered in the process of elaboration and in which the *explanans* contains both (a) *other discovered structures* and (b) *mentally created non-observational entities* (“Theoretical entities”).

Theoretical meaning is constituted by the network of relations among these elements of explanation.

The ‘other discovered structures’ in the theory play the role of connecting links between theoretical entities and the level of physical fact of discovered structure.

The ‘theoretical entities’ contained in the *explanans* are postulated because of their explanatory power; they provide a content of theoretical meaning from which the *explanandum* can be deduced.

Blackwell concludes that the process of transformation has a dual aspect: it is productive both (1) of an explanatory system and (2) of theoretical entities.

These are both transformations because neither is a discovered structure.

An explanatory system is a logical pattern of inference; it is not an articulated relatedness of the dictates of nature.

Theoretical entities are produced by a manipulation and refashioning of the content of discovered structures.

The main *burden of explanation falls on the theoretical entities*; their content will provide the sources from the *explanandum* can be deductively derive.

In such transformation, the mind-nature confrontation reaches a new level of adaptation in which the mind is considerably more active.

The Elements of Transformation

The process of transformation begins as the mind actively manipulates/restructures those physical structures which were originally discovered at the level of elaboration.

1. *Idealization*: the conversion of discovered structures into forms which are not, and often cannot be, actual physical facts.

The resultant entity is not an actual physical fact, in the sense that there is no empirical evidence to ground this entity as such in the dictates of nature.

Examples:

- The substitution of a *limit* for the process of approaching a limit involves a qualitative shift of meaning by which a discovered structure is converted into an idealized theoretical entity.
- The *exclusion of non-negligible factors* from the description of a physical situation.
- The symbolization of a physical structure, with the symbol itself becoming the direct object of scientific concern.

E.g., the introduction of a constant into an equation.

- The *thought experiment*: actual experimental conditions are translated into contrived situations which are not physically realizable and may even be impossible.

These examples all display a common pattern, the transformation of a discovered structure into a new form. The resultant entities are not physical facts, but are explanatory only insofar as they are placed in a systematic relation to the discovered structures from which they arose.

2. *Creative Postulation*: The formulation of theoretical entities by the stipulation of a set of components which, if assumed, will enable the deduction and prediction of observed physical facts.

Such creative postulations of the mind are potentially infinite in number; but the demands for explanatory power are built into the act of postulation itself, such that the theoretical entities are formulated precisely to exercise a specific explanatory function.

The mind creates theoretical entities here by using virtually any and all material available from previous knowledge; but it does this with a specific explanatory problematic in mind, which from the beginning considerably limits the options to be considered.

This offers a wide range for gifted insight.

It is possible to distinguish two ways in which this process occurs:

i. Postulation of *hypothetical physical entities*.

This is evidenced in modern science's faith in micro-reductioning, i.e., a commitment to the explanatory ideal of reducing perceived objects and events to the level of the very small.

Such microscopic entities are endowed with exactly those qualities which, if granted, will enable the deduction and prediction of macroscopic objects and events.

Classic case = atomic theory and subatomic particles.

There is a strong tendency to objectify such entities in a naively realistic sense.

The resulting world picture has had a pervasive influence on modern scientific culture; but such a view tends to neglect the origins and functions of theoretical entities.

ii. Postulation of *mathematical formalisms*.

Associations are seen between the derived consequences of the formalism and physical matters of fact.

3. Substitution through Analogy.

Prior knowledge serves as a fruitful source of suggestion in the search for explanation.

This begins with the recognition that the problematic before one bears resemblance to another problematic which has already been solved.

Thus, a theoretical explanation is transferred from one domain to another.

This process has a dual element: recognition/transfer.

Two types of similarities are relevant:

- i. Based on analogous meaning content;
- ii. Based on formal symmetries.

Hope for an ultimate unification of scientific knowledge hinges largely on successful perception of analogies at the theoretical level.

Whenever analogy is used, a body of physical fact has acquired a theoretical meaning which it previously did not possess; this introduces a new interpretation.

Closely related to this is the introduction of theoretical models.

E.g., the planetary model of the atom.

Theoretical Discovery

Theoretical discovery is the *grasping of the explanation* of a previously discovered structure in terms of its deductive derivation from a set of theoretical entities.

Thus, it is a matter of the interpretation of facts.

Chapter SEVEN: The Ontological Status of Scientific Objects

Questions as to the *reality* of the objects of scientific discourse arise soon after the first reflection on the nature and content of scientific knowledge, but they cannot be intelligently asked/answered without a great deal of prior reflection on and analysis of the nature of science.

Further, there is considerable disagreement among analysts of science in answering such questions and even regarding the very legitimacy of the questions.

There are two extreme positions:

1. Those who regard scientific objects as the “really real” and as being causally productive of the appearances which things have in human experience.
2. Those who regard scientific objects as merely human creations or conventions.

And there are a wide range of interpretations between these two extremes.

Given this disagreement, it must be remembered that most of the truly fundamental human concerns have this unsettled/debatable air about them and final solutions are not forthcoming; still, the attempt at clarification can/does progress.

The approach to science from the point of view of the act of discovery puts the question in a special light.

By retracing the process of discovery in reverse, the various levels of meaning in scientific objects can both be related to each other and to the common matrix of human experience from which science takes its beginnings. In this way an avenue is opened for considering the question of the reality of such objects.

A Refinement of the Question

Ontological reality may first be defined negatively as a *condition opposed to purely mental/intentional reality*.

At first approximation, this question becomes the problem of *whether and in what sense scientific objects exist in nature*.

But before this is understood too simply, it must be recalled that nature-in-itself is an abstraction; man possesses no privileged access to nature independent of human experience.

“Nature” is an essentially relational entity – incomplete in itself – which requires mind as its complement.

Both the dictates-of-nature and the functions-of-mind are operative at both levels of discovery – elaboration and transformation – with the dictates of nature having a more predominant role at the first level and the functions of mind being more assertive at the second level.

“Nature” has a different meaning at the various stages of the process of adaptation.

Thus, appeal to “nature” as criterion of the ontological status of scientific objects is complicated by the fact that nature as adapted can and does have different meanings.

Also, scientific knowledge does not constitute our entire understanding of nature; there is also an immediate awareness which becomes the content of common-sense knowledge.

Because this adaptation theory does not result in a single/fixed conception of nature, the question of the ontological status of scientific objects is very *complex*.

The *plurality of meanings* of “nature” means that there is no simple affirmative/negative answer to the question of a scientific object existing in nature.

As one shifts the context from one meaning of “nature” to another, quite different answers are possible and to be expected.

However, these various meanings of “nature” have relative priorities.

Nature as immediately perceived possesses a special status as the primary criterion for the evaluation of the ontological status of scientific objects.

Thus: *a scientific object is ontologically real insofar as it expresses a dictate of nature*.

What is called for is a retracing of the process of discovery to sort out the dictates of nature and the functions of mind whose initial coalescence generated the given scientific object.

The first approximation to a restatement of the question still assumes the possibility of a direct “yes/no” answer; it remains too much of a simplification.

To phrase the question in such a way that it asks for a simple “yes/no” answer is to assume that the issue of the ontological status of scientific objects is a matter of

deciding whether there is a one-to-one correspondence between scientific objects and entities in nature. Such is not the case.

The question rather should be to *what degree does the scientific object represent the content of nature as it is immediately experienced?*

“To what degree do scientific objects express the dictates of nature?”

Thus, a scientific object would be real, not as a thing-in-itself beyond experience, but as a physically meaningful content of the dictates of nature.

Accordingly, not all scientific objects possess the same degree of reality; they will possess *varying degrees of ontological reality*, depending on where they are located in the continuous spectrum of discovery.

In no case do we have an object either fully real in the literal sense of fully non-real.

Conclusion: *A scientific object is ontologically real insofar as it expresses the dictates of nature rather than the functions of mind.*

What is called for is a retracing of the process of discovery to uncover the dictates of nature which remain, as a residue in the scientific object.

The Reality of Theoretical Entities

Even at the level of elaboration, the functions-of-mind influence the dictates-of-nature. E.g., the universality of discovered structures is not a property of the dictates of nature as such, since whatever exists concretely in nature is singular, not universal.

Nevertheless, the influences introduced by the functions-of-mind at the level of discovered structures are comparatively easy to identify and to distinguish from the dictates of nature.

At the level of theoretical entities, the problems are much more complex.

Part of the complication is that such entities are often constructed so that they can be ‘pictures’; as a result, the implication is easily drawn that these are actual physical objects in nature.

As postulated objects, theoretical entities are thought of as though they were really real in a literal sense, but this cannot justify the inference that they are ontologically real in a direct sense, without violating the limitations of human knowledge.

Direct scientific realism makes this unjustified inference.

As noted earlier, the question is not a matter of finding an object existing in nature-in-itself to which a scientific object corresponds. The issue is the degree to which such an object expresses the dictates of nature as found in immediate experience.

And as one extreme is direct scientific realism, an opposite extreme denies any ontological reality to such objects: conventionalism.

But the theory of discovery reveals that theoretical entities always bear some residue of physical meaning.

The question is *how* do the entities relate to nature: Are the entities real in the sense of expressing the dictates of nature at the levels of immediate experience and discovered structures?

Blackwell's answer is "a qualified 'yes'": Theoretical entities are ontologically real insofar as they indirectly symbolize those dictates of nature which were transformed by the creative functions of mind in the initial genesis of the theoretical entity.

E.g., an electron is ontologically real insofar as it expresses the dictates of nature involved in various phenomena.

Cultural Fallout

The popularization of science tends to attribute a direct and naively realistic status to theoretical entities.

Often, the models used in the formulation of scientific theories tend to become objectified.

This, in turn, plays a dominating role in determining the world view of modern culture.