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The Structure of Scientific Revolutions by Thomas Kuhn

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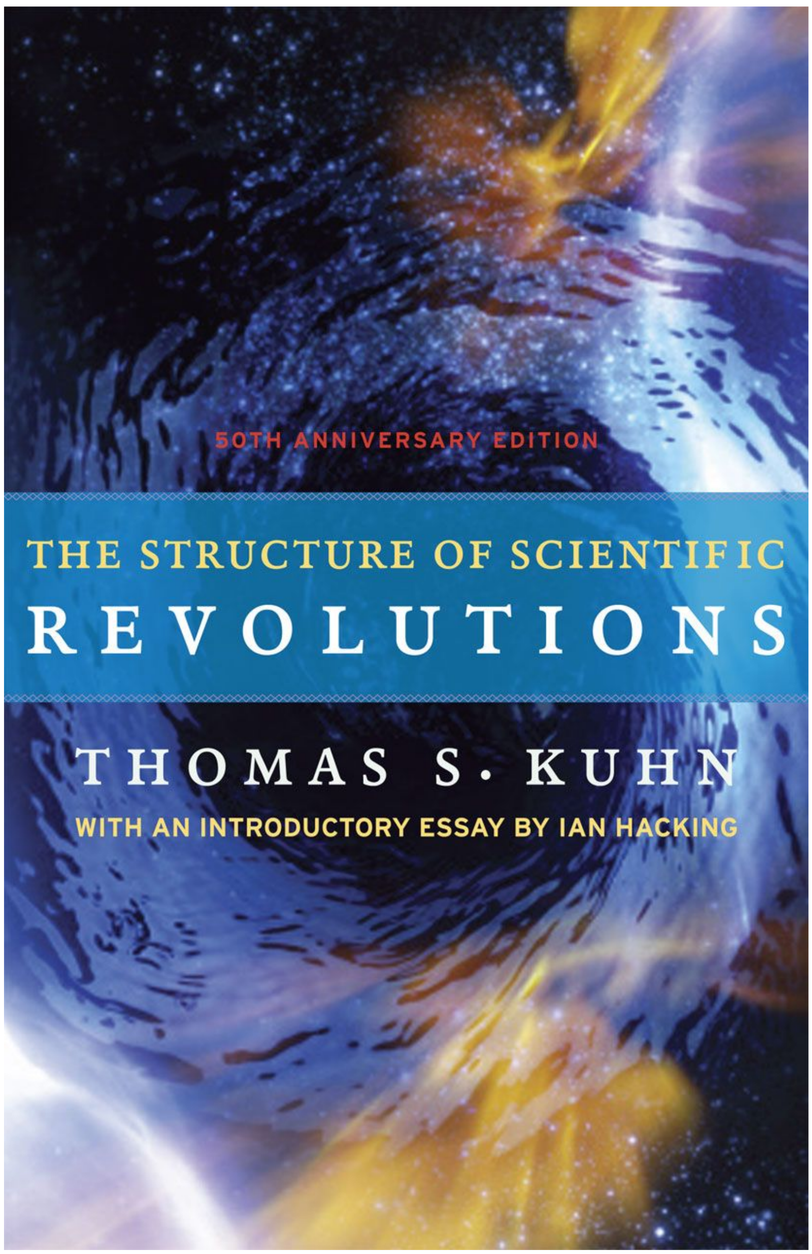

Prelude: Karl Popper

Before Kuhn, Karl Popper (1902-94) was the most influential philosopher of science. According to his perspective cause and effect were mere appearance in indeterminacy was the root of reality. First scientist must frame bold conjectures, as testable as possible, and inevitably find them wanting. Does conjectures are then refuted and a new conjecture must be found that fits the facts. **Hypotheses can count as "scientific" only if they are falsifiable**. Kuhn's emphasis on revolutions can be seen as the next stage after Popper's refutations. The structure of scientific revolutions, in short, tracks the following three-step process:

1. **Normal science** is conducted on the basis of a central paradigm and a dedication to solving the puzzles that revolve around this paradigm.
2. A series of experimental anomalies lead to a **crisis** in the scientific community.
3. A **revolution** takes place, whereby the crisis is resolved by the emergence of a new paradigm, which is incommensurable to the old paradigm.

The Nature of Normal Science

Normal science, in the most general sense, is any research that is firmly based upon one or more past scientific paradigms that was foundational to the field. **Paradigms** are called as such because (1) they were sufficiently **unprecedented** to attract an enduring group of adherents away from competing modes of scientific activity and (2) because they are sufficiently **open-ended** to leave all sorts of problems for the redefined group of practitioners to resolve. Paradigms provide models from which spring particular coherent traditions of scientific research. Scientists whose research is based on shared paradigms are committed to the same rules and standards for scientific practice. The consensus it produces is a prerequisite for the genesis and continuation of a particular research tradition.

The Pre-Paradigm Void

In the absence of a paradigm, all of the facts that could possibly pertain to the development of it given science are likely to seem equally relevant. As a result, **early fact-gathering is a far more random activity** than the one that subsequent scientific development makes familiar. Furthermore, in the absence of a reason for seeking some particular form of more recondite information, fact-gathering is usually restricted to the wealth of data that lie ready to hand. Since any description must be partial, the typical natural history **often omits from its immensely circumstantial accounts those details that later scientists will find sources of important illumination**.

Only very occasionally, as in the cases of ancient statistics, dynamics, and geometrical optics, do facts collected with so little guidance from pre-established theory speak with sufficient clarity to permit the emergence of a first paradigm. This is the situation that creates the schools characteristic of the early stages of a science's development.

It is no wonder that in the early stages of development of any science, different men confronting the same range of phenomena might describe and interpret them in different ways. What is surprising and, perhaps, unique to the field we call science is that such initial divergences largely disappear. Furthermore, their disappearance is usually caused by the triumph over one of the pre-paradigm schools which, because of its own characteristic beliefs and preconceptions, emphasized only some special part the to sizable and inchoate pool of information.

When an individual or group first produces a synthesis that is able to attract most of the next generations practitioners, the older schools gradually disappear. In part, their disappearance is caused by their members' conversion to the new paradigm. Those unwilling or unable to accommodate their work to its view must either proceed in isolation or attach themselves to some other group.

The new paradigm provides great benefit to its practitioners. When the individual scientists can take a paradigm for granted, they need not attempt to build his field anew, starting from first principles and justifying the use of each concept introduced. The creative scientists can begin their research where it leaves off and the concentrate exclusively upon the subtlest and most esoteric aspects of the natural phenomena that concern his group.

A New Paradigm Arises from Fundamental Rules

In this case, we apply a broader use of the term 'rule' to one that equates more with 'established viewpoint' or 'preconception'. The search for body of rules that constitute a given normal research tradition becomes a source of continual and deep frustration, although the search is greatly muted during periods in which the prevailing paradigm is stable.

In scientific education, **scientists work from models acquired through exposure to the literature, often without quite knowing or needing to know what characteristics have given these models the status of community paradigms**. The coherence displayed by the research tradition in which they participate in may not imply even the existence of an underlying body of rules and assumptions that additional historical or philosophical investigation might uncover.

Scientists typically learn concepts, laws, and theories together with applications to some concrete range of natural phenomena. The process of learning a theory depends upon the study of its applications, including practice problem solving both of the pencil and paper and with instruments in the laboratory. The process of learning by doing continues throughout the progression of professional initiation. As a student precedes from his freshman course to his doctoral dissertation, the problems assigned to him become more complex unless completely precedented. Yet they continue to be closely modeled on previous achievements. Many scientists talk easy and well about the particular individual hypotheses that underlie a concrete piece of current research, they are **little better than layman at characterizing the established basis of their field, it's legitimate problems and methods**. If they have learned such abstractions at all, they show it mainly through their ability to do successful research.

This process can proceed without rules only so long as the relevant scientific community accepts, without question, the particular problem solutions already achieved. **Rules will become increasingly important, however, whenever paradigms or models are felt to be insecure**.

The pre-paradigm period is regularly marked by frequent and deep debate over legitimate methods, problems, and standards of solutions. The almost non-existent during periods of normal science, such debates recur regularly just before and during scientific revolutions, the periods when paradigms our first under attack and then subject to change. For example, the transition from Newtonian to Quantum Mechanics evoke too many debates about both the nature and the standards of physics, some of which continue to this day. When scientists disagree about whether the fundamental problems of their field have been solved, the search for rules games of function that it does not ordinarily possess.

The Anatomy of Normal Science Research

Normal science does not aim at novelty, although, novelty can emerge from the confirmation of theories already held and it primarily consists of working away at a few puzzles that are left open in the current field of knowledge. If you look at any research Journal you'll find three types of problems addressed:

1. **Determination of Significant Facts**: Theory will use certain qualities or phenomena to adequately describe and qualitatively tells us what to expect. Measurement and other procedures determine the facts more precisely. Again and again a complex special apparatus has been designed for such purposes. Invention, construction, and deployment of such an apparatus has demanded first-rate talent, a great time dedication, and considerable financial backing. Some scientists have acquired great reputations, not from any novelty of their discoveries, but from the precision, reliability, and scope of the methods they developed for the redetermination of a previously known sort of fact.
2. **Matching of Facts With Theory**: If known observations don't quite tally with theory, one must either tidy of the theory or show that the experimental data were defective.
3. **Articulation of Theory**: This type consists of empirical work undertaken to articulate the paradigm theory, resolving some of its residual ambiguities in permitting the solution of problems to which it had previously only drawn attention. If the theory lacks a solid mathematical formulation, one one must be formulated, in order to comprehend its consequences.

To be accepted as a paradigm, a theory must seem better than its competitors, but it need not explain all the facts with which it can be confronted. Both fact collection and theory articulation should be highly directed activities. This sentiment matches Francis Bacon's acute methodological dictum: "**Truth emerges more readily from error than from confusion**". Like an accepted judicial decision in the common law, **a paradigm is an object for further articulation and specification under new and more stringent conditions**. These studies make for a more applicable paradigm by increasing the extent of the match between the facts and the paradigms predictions.

One of the things the scientific community requires with a paradigm is a criterion for choosing problems that can be assumed to have solutions. To a great extent these are the only problems that the community will admit as scientific or encourage its members to undertake. Other problems, including many that had previously been standard, are rejected as metaphysical, are relegated to another discipline, or are sometimes classified as too problematic to be worth the time. A paradigm can, for that matter, insulate the community from those socially important problems that are not reducible to the puzzle form because they cannot be stated in terms of the conceptual and instrumental tools that the paradigm supplies.

A man may be attracted to science for all sorts of reasons. Among them are the desire to be useful, the excitement of exploring new territory, the hope of finding order, and the drive to test established knowledge. Although the result is occasional frustration, there is good reason why motives like these should first attract him and then lead him on. Nevertheless, the individual engaged on a normal research problem is almost never doing any one of these things. What **challenges him is the conviction that if only he is skilled enough he will succeed in solving a puzzle that no one before has solved**.

Anomaly and the Emergence of Scientific Discoveries

Although normal signs does not aim at novelties of fact or theory, new and unsuspected phenomena can be repeatedly uncovered. Produced inadvertently buy a game played under one set of rules, there is simulation requires the elaboration of another set. Assimilating a new sort of fact demands more than attitude adjustment of theory. Until this scientist has learn to see nature in a different way, the new fact is not quite a scientific fact at all.

Discovery is not the sort of process about which the question is appropriately asked. The fact that it is asked is a symptom of something ask you in the image of science that gives discovery so fundamental a role. A phrase like, “oxygen was discovered”, misleads by suggesting that discovering something is a simple act that is comparable to our usual concept of seeing. That is why we so readily assume that discovering, like seeing or touching, should be unequivocally attributable to an individual and to a moment in time. **Discovering a new sort of phenomenon is necessarily a complex, one which involves recognizing both *that* something is and *what* it is**.

The value placed upon a new phenomenon and, thus, upon it's discover varies with our estimate of the extent to which the phenomenon violated paradigm induced anticipations. The perception of anomaly - the phenomenon for which is paradigm had not readied the investigator - plays an essential role in preparing the way for perception of novelty.

A classic case of an anomaly is the discovery of x-rays by the German physicist Wilhelm Roentgen in 1895. Roentgen interrupted a normal investigation of cathode rays because he had noticed that a barium platinocyanide screen at some distance from his shielded apparatus glowed when the discharge was in process. Further investigations indicated that the cause of the glow came in straight lines from the cathode ray tube, cast shadows, and could not be deflected by magnets. After announcing his discovery, x-rays we're greeted not only with surprise but with shock. Lord Kelvin that first pronounced them an elaborate hoax.

Although X-rays were not prohibited by established theory, they violated deeply entrenched expectations; expectations that were implicit in the design and interpretation of established laboratory procedures. **The decision to employ a particular piece of apparatus and to use it in a particular way carries an assumption that only certain sorts of circumstances will arise**. Paradigm procedures and applications are as necessary to science as paradigm laws and theories, and they have the same effects. Inevitably they restrict the phenomenological field accessible for scientific investigation at a given time.

In science, novelty emerges only with difficulty, manifested by resistance against a background provided by expectation. **By ensuring that the paradigm will not be too easily surrendered, resistance guarantees that scientists will not be lightly disgraced** and that anomalies that lead to Paradigm change will penetrate existing knowledge to the core. Initially, only the anticipated are experienced even under circumstances where anomaly is later to be observed. Further acquaintance, however, does result in awareness of something wrong or does relate the effect to something that has gone wrong before. That **awareness of anomaly opens a period in which conceptual categories are adjusted until the initially anomalous has become anticipated**. At this point the discovery has been completed.

The transition from a paradigm in crisis to a new one from which a new tradition of normal science can emerge is far from a cumulative process, one achieved by an articulation or extension of the old paradigm. Rather it is a reconstruction of the field from new fundamentals, a reconstruction that changes some of the field's most elementary theoretical generalizations as well as many of its methods and applications. During the transition. There will be a large but never complete overlap between the problems that can be solved by the old and buy the new paradigm. But there will also be a decisive difference in the modes of solution. When the transition is complete, the profession will have changed its view of the field, its methods, and it's goals.

However, these considerations beg the question: how do scientists proceed only aware only that something has gone fundamentally wrong? More often than not, a new paradigm emerges in an embryo state before a crisis has developed far or been explicitly recognized. **Faced with an admittedly fundamental anomaly in theory, the scientist's first effort will often be to isolate it more precisely and to give it structure**. He will push the rules of normal science harder than ever to see just where and how far they can be made to work. Simultaneously, he will still ways for magnifying the breakdown, or making it more striking and perhaps also more suggestive than it had been when displayed in experiments, the outcome of which was thought to be known in advance. He might often seem like a man searching at random, trying experiments just to see what will happen, looking for an effect whose nature he cannot quite guess. **Since no experiment can be conceived without some sort of theory, the scientist in crisis will constantly try to generate**

speculative theories that may disclose the road to a new paradigm that, if unsuccessful, can be surrendered with relative ease.

Revolution and Paradigm Shift

Led by a new paradigm, scientists adopt new instruments and look in new places. Even more important, during revolutions **scientists see new and different things when looking with familiar instruments in the places they have looked before**. Therefore, at times of revolution, the scientist's perception of his environment must be re-education - in some familiar situations, he must learn to see a new gestalt.

This conceptual shift can be analogized to an experimental subject who puts on goggles fitted with inverting lenses. He initially sees the entire world upside down. At the start, his perceptual apparatus functions in the absence of the goggles. The result is extreme disorientation and, perhaps, an acute personal crisis. However, the subject's visual field eventually flips over. Thereafter, objects are again seen as thei had been before the goggles were put on. The assimilation of a previously anomalous visual field has reacted upon and changed the field itself. Similarly, **the scientist appears to work in a different world after a paradigm shift, although the world itself remains unchanged**.

When considering the nature of revolutions in this regard, it becomes increasing clear: **theories are simply man-made interpretations of a certain data set**. It is difficult to make nature fit a paradigm. That is why the puzzles of normal science are so challenging and also why measurements undertaken without a paradigm so seldom lead to any conclusions at all.

Pedagogical Lessons of Revolutions

Textbooks aim to to communicate the vocabulary and syntax of contemporary scientific language. However, being pedagogical vehicles for the perpetuation of normal science, have to be rewritten whenever the language, problem structure, or standards of normal science change. Once rewritten, **textbooks inevitably disguise the role and, perhaps, the very existence of the revolutions that produced them**.

Because they aim quickly to acquaint the student with what the contemporary scientific community thinks it knows, textbooks treat the various experiments, concepts, laws, and theories of the current normal science as if they were particular objectives that scientists aimed for. But that is not the way that science develops. **Theories do not evolve piecemeal to fit facts that were there all the time**. Rather, **they emerge together with the facts they fit from a revolutionary reformulation, which sprouted when the knowledge-mediated relationship between the scientist and nature was not quite the same**.

References

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