The Structure of Scientific Revolutions

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Outline and Study Guide
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Chapter I - Introduction: A Role for History.

Kuhn begins by formulating some assumptions that lay the foundation for subsequent discussion and by briefly outlining the key contentions of the book.

A. A *scientific community* cannot practice its trade without some set of *received beliefs* (p. 4).
   1. These beliefs form the foundation of the "educational initiation that prepares and licenses the student for professional practice" (5).
   2. The nature of the "rigorous and rigid" preparation helps ensure that the received beliefs exert a "deep hold" on the student's mind.

B. *Normal science* "is predicated on the assumption that the scientific community knows what the world is like" (5)—scientists take great pains to defend that assumption.

C. To this end, "normal science often suppresses fundamental novelties because they are necessarily subversive of its basic commitments" (5).

D. *Research* is "a strenuous and devoted attempt to force nature into the conceptual boxes supplied by professional education" (5).

E. A *shift* in professional commitments to shared assumptions takes place when an *anomaly* "subverts the existing tradition of scientific practice" (6). These shifts are what Kuhn describes as *scientific revolutions*—"the tradition-shattering complements to the tradition-bound activity of normal science" (6).
   1. New assumptions (paradigms/theories) require the reconstruction of prior assumptions and the reevaluation of prior facts. This is difficult and time consuming. It is also strongly resisted by the established community.
   2. When a shift takes place, "a scientist's world is qualitatively transformed [and] quantitatively enriched by fundamental novelties of either fact or theory" (7).

Chapter II - The Route to Normal Science.

In this chapter, Kuhn describes how paradigms are created and what they contribute to scientific (disciplined) inquiry.

A. *Normal science* "means research firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice" (10).
   1. These *achievements* must be

        a. sufficiently *unprecedented* to attract an enduring group of adherents away from competing modes of scientific activity and
        b. sufficiently *open-ended* to leave all sorts of problems for the redefined group of practitioners (and their students) to resolve, i.e., research.
    2. These achievements can be called *paradigms* (10).
    3. "The road to a firm research consensus is extraordinarily arduous" (15).

B. "*The successive transition from one paradigm to another via revolution is the usual developmental pattern of mature science"* (12).

C. Students study these paradigms in order to become members of the particular scientific community in which they will later practice.
    1. Because the student largely learns from and is mentored by researchers "who learned the bases of their field from the same concrete models" (11), there is seldom disagreement over fundamentals.
    2. *Men whose research is based on shared paradigms are committed to the same rules and standards for scientific practice* (11).
    3. A shared commitment to a paradigm ensures that its practitioners engage in the paradigmatic observations that its own paradigm can do most to explain (13), i.e., investigate the kinds of research questions to which their own theories can most easily provide answers.

D. "It remains an open question what parts of social science have yet acquired such paradigms" (15). [psychology? education? teacher education? sociology?]

E. Paradigms help scientific communities to *bound* their discipline in that they help the scientist to
    1. create avenues of inquiry.
    2. formulate questions.
    3. select methods with which to examine questions.
    4. define areas of relevance.
    5. [establish/create meaning?]

F. "In the absence of a paradigm or some candidate for paradigm, all the facts that could possibly pertain to the development of a given science are likely to seem equally relevant" (15).

G. *A paradigm is essential to scientific inquiry*—"no natural history can be interpreted in the absence of at least some implicit body of intertwined theoretical and methodological belief that permits selection, evaluation, and criticism" (16-17).

H. How are paradigms created, and how do scientific revolutions take place?
    1. Inquiry begins with a random collection of "mere facts" (although, often, a body of beliefs is already implicit in the collection).
        a. During these early stages of inquiry, different researchers confronting the same phenomena describe and interpret them in different ways (17).
        b. In time, these descriptions and interpretations entirely disappear.
    2. A *preparadigmatic* school (movement) appears.
        a. Such a school often emphasizes a special part of the collection of facts.
        b. Often, these schools vie for preeminence.
    3. From the competition of preparadigmatic schools, one paradigm emerges—"To be accepted as a paradigm, a theory must seem better than its competitors, but it need not, and in fact never does, explain all the

facts with which it can be confronted" (17-18), thus making research possible.

4. As a paradigm grows in strength and in the number of advocates, the preparadigmatic schools (or the previous paradigm) fade.
    a. "When an individual or group first produces a synthesis able to attract most of *the next generation's* practitioners, the older schools gradually disappear" (18).
    b. Those with "older views . . . are simply *read out* of the profession and their work is subsequently ignored. If they do not accommodate their work to the new paradigm, they are doomed to isolation or must attach themselves to some other group" (19), or move to a department of philosophy (or history).
5. *A paradigm transforms a group into a profession or, at least, a discipline* (19). And from this follow the
    a. formation of specialized journals.
    b. foundation of professional societies (or specialized groups within societies—SIGs).
    c. claim to a special place in academe (and academe's curriculum).
    d. fact that members of the group need no longer build their field anew—first principles, justification of concepts, questions, and methods. Such endeavors are left to the theorist or to writer of textbooks.
    e. promulgation of scholarly articles intended for and "addressed only to professional colleagues, [those] whose knowledge of a shared paradigm can be assumed and who prove to be the only ones able to read the papers addressed to them" (20)—preaching to the converted.
    f. (discussion groups on the Internet and a listerserver?)

I. *A paradigm guides the whole group's research*, and it is this criterion that most clearly proclaims a field a science (22).

Chapter III - The Nature of Normal Science.

If a paradigm consists of basic and incontrovertible assumptions about the nature of the discipline, what questions are left to ask?

A. When they first appear, paradigms are limited in scope and in precision.
B. "Paradigms gain their status because they are more successful than their competitors in solving *a few problems* that the group of practitioners has come to recognize as acute" (23).
    1. But *more successful* does not mean *completely successful with a single problem or notably successful with any large number* (23).
    2. Initially, a paradigm offers the *promise* of success.
    3. Normal science consists in the actualization of that promise. This is achieved by
        a. extending the knowledge of those facts that the paradigm displays as particularly revealing,
        b. increasing the extent of the match between those facts and the paradigm's predictions,
        c. and further articulation of the paradigm itself.

4. In other words, there is a good deal of *mopping-up* to be done.
    a. Mop-up operations are what engage most scientists throughout their careers.
    b. *Mopping-up is what normal science is all about!*
    c. This *paradigm-based research* (25) is "an attempt to force nature into the preformed and relatively inflexible box that the paradigm supplies" (24).
        i. no effort made to call forth new sorts of phenomena.
        ii. no effort to discover anomalies.
        iii. when anomalies pop up, they are usually discarded or ignored.
        iv. anomalies usually not even noticed (tunnel vision/one track mind).
        v. no effort to invent new theory (and no tolerance for those who try).
        vi. *"Normal-scientific research is directed to the articulation of those phenomena and theories that the paradigm already supplies"* (24).
        vii. "Perhaps these are defects . . . "
            1. ". . . but those restrictions, born from confidence in a paradigm, turn out to be essential to the development of science. By focusing attention on a small range of relatively esoteric problems, the paradigm forces scientists to investigate some part of nature in a detail and depth that would otherwise be unimaginable" (24).
            2. . . . and, when the paradigm ceases to function properly, scientists begin to behave differently and the nature of their research problems changes.
    d. Mopping-up can prove fascinating work (24). [You do it. We all do it. And we love to do it. In fact, we'd do it for free.]

C. The principal problems of normal science.
1. *Determination of significant fact.*
    a. A paradigm guides and informs the *fact-gathering* (experiments and observations described in journals) decisions of researchers?
    b. Researchers focus on, and attempt to increase the accuracy and scope of, facts (constructs/concepts) that the paradigm has shown to be particularly revealing of the nature of things (25).
2. *Matching of facts with theory.*
    a. Researchers focus on facts that can be compared directly with predictions from the paradigmatic theory (26)
    b. Great effort and ingenuity are required to bring theory and nature into closer and closer agreement.
    c. A paradigm sets the problems to be solved (27).
3. *Articulation of theory.*
    a. Researchers undertake empirical work *to articulate the paradigm theory* itself (27)—resolve residual ambiguities, refine, permit solution of problems to which the theory had previously only drawn attention. This articulation includes
        i. determination of universal constants.

    ii. development of quantitative *laws*.
    iii. selection of ways to apply the paradigm to a related area of interest.
  b. This is, in part, a problem of *application* (but only in part).
  c. Paradigms must undergo *reformulation* so that their tenets closely correspond to the natural object of their inquiry (*clarification by reformulation*).
  d. "The problems of paradigm articulation are simultaneously theoretical and experimental" (33).
  e. Such work should produce new information and a more precise paradigm.
  f. This is the primary work of many sciences.

D. *To desert the paradigm is to cease practicing the science it defines* (34).

Chapter IV - Normal Science as Puzzle-solving.

Doing research is essentially like solving a puzzle. Puzzles have rules. Puzzles generally have predetermined solutions.

A. A striking feature of doing research is that the aim is to discover what is known in advance.
  1. This in spite of the fact that the range of anticipated results is small compared to the possible results.
  2. When the outcome of a research project does not fall into this anticipated result range, it is generally considered a failure, i.e., when "significance" is not obtained.
     a. Studies that fail to find the expected are usually not published.
     b. The proliferation of studies that find the expected helps ensure that the paradigm/theory will flourish.
  3. Even a project that aims at paradigm articulation does not aim at *unexpected* novelty.
  4. "One of the things a scientific community acquires with a paradigm is a criterion for choosing problems that, while the paradigm is taken for granted, can be assumed to have solutions" (37).
     a. The *intrinsic value* of a research question is not a criterion for selecting it.
     b. The assurance that the question has an answer is the criterion (37).
     c. *"The man who is striving to solve a problem defined by existing knowledge and technique is not just looking around. He knows what he wants to achieve, and he designs his instruments and directs his thoughts accordingly"* (96).

B. So why do research?
  1. Results add to the scope and precision with which a paradigm/theory can be applied.
  2. The *way* to obtain the results usually remains very much in doubt—this is the *challenge of the puzzle*.
  3. Solving the puzzle can be fun, and *expert puzzle-solvers* make a very nice living.

C. To classify as a puzzle (as a genuine research question), a problem must be characterized by more than the assured solution.
    1. There exists a strong network of commitments—conceptual, theoretical, instrumental, and methodological.
    2. There are "rules" that limit
        a. the nature of acceptable solutions—there are "restrictions that bound the admissible solutions to theoretical problems" (39).
            i. Solutions should be consistent with paradigmatic assumptions.
            ii. There are *quasi-metaphysical* commitments to consider.
            iii. There may also be historical ties to consider.
        b. the steps by which they are to be obtained (methodology).
            i. commitments to preferred types of instrumentations.
            ii. the ways in which accepted instruments may legitimately be employed.

D. Despite the fact that novelty is not sought and that accepted belief is generally not challenged, the scientific enterprise *can* and *does* bring about such unexpected results.

Chapter V - The Priority of Paradigms.

How can it be that "*rules derive from paradigms, but paradigms can guide research even in the absence of rules*" (42).

A. The paradigms of a mature scientific community can be determined with relative ease (43).

B. The "rules" used by scientists who share a paradigm are not easily determined. Some reasons for this are that
    1. scientists can disagree on the *interpretation* of a paradigm.
    2. the existence of a paradigm need not imply that any full set of rules exist.
    3. scientists are often guided by *tacit knowledge*—knowledge acquired through practice and that cannot be articulated explicitly (Polanyi, 1958).
    4. the attributes shared by a paradigm are not always readily apparent.
    5. "paradigms may be prior to, more binding, and more complete than any set of rules for research that could be unequivocally abstracted from them" (46).

C. Paradigms *can* determine normal science without the intervention of discoverable rules or shared assumptions (46). In part, this is because
    1. it is very difficult to discover the rules that guide particular normal-science traditions.
    2. scientists never learn concepts, laws, and theories in the abstract and by themselves.
        a. They generally learn these with and through their applications.
        b. New theory is taught in tandem with its application to a concrete range of phenomena.
        c. "The process of learning a theory depends on the study of applications" (47).
        d. The problems that students encounter from freshman year through doctoral program, as well as those they will tackle during

achievements.

their careers, are always closely modeled on *previous achievements*.

3. Scientists who share a paradigm generally accept without question the particular problem-solutions already achieved (47).
4. *Although a single paradigm may serve many scientific groups, it is not the same paradigm for them all.*
    a. Subspecialties are differently educated and focus on different applications for their research findings.
    b. A paradigm can determine several traditions of normal science that overlap without being coextensive.
    c. Consequently, changes in a paradigm affect different subspecialties differently—"A revolution produced within one of these traditions will not necessarily extend to the others as well" (50).

D. *When scientists disagree about whether the fundamental problems of their field have been solved, the search for rules gains a function that it does not ordinarily possess* (48).

Chapter VI - Anomaly and the Emergence of Scientific Discoveries.

If normal science is so rigid and if scientific communities are so close-knit, how can a paradigm change take place? This chapter traces paradigm changes that result from *discovery* brought about by encounters with *anomaly*.

A. Normal science does not aim at novelties of fact or theory and, when successful, finds none.
B. Nonetheless, *new and unsuspected phenomena are repeatedly uncovered by scientific research, and radical new theories have again and again been invented by scientists* (52).
C. Fundamental novelties of fact and theory bring about paradigm change.
D. So how does paradigm change come about?
    1. *Discovery*—novelty of fact.
        a. Discovery begins with the awareness of *anomaly*.
            i. The recognition that nature has violated the paradigm-induced expectations that govern normal science.
            ii. A phenomenon for which a paradigm has not readied the investigator.
        b. Perceiving an anomaly is essential for perceiving *novelty* (although the first does not always lead to the second, i.e., anomalies can be ignored, denied, or unacknowledged).
        c. The area of the anomaly is then explored.
        d. The paradigm change is complete when the paradigm/theory has been adjusted so that the anomalous become the expected.
        e. The result is that the scientist is able "to see nature in a different way" (53).
        f. But careful: Discovery involves an extended process of *conceptual assimilation*, but assimilating new information does not always lead to paradigm change.

2. *Invention*—novelty of theory.
    a. *Not all theories are paradigm theories.*
    b. Unanticipated outcomes derived from theoretical studies can lead to the perception of an anomaly and the awareness of novelty.
    c. How paradigms change as a result of invention is discussed in greater detail in the following chapter.

E. The process of paradigm change is closely tied to the nature of perceptual (conceptual) change in an individual—*Novelty emerges only with difficulty, manifested by resistance, against a background provided by expectation* (64).

F. Although normal science is a pursuit not directed to novelties and tending at first to suppress them, it is nonetheless very effective in causing them to arise. Why?
1. An initial paradigm accounts quite successfully for most of the observations and experiments readily accessible to that science's practitioners.
2. Research results in
    a. the construction of elaborate equipment,
    b. development of an esoteric and shared vocabulary,
    c. refinement of concepts that increasingly lessens their resemblance to their usual common-sense prototypes.
3. This professionalization leads to
    a. immense restriction of the scientist's vision, rigid science, and resistance to paradigm change.
    b. a detail of information and precision of the observation-theory match that can be achieved in no other way.
        i. New and refined methods and instruments result in greater precision and understanding of the paradigm/theory.
        ii. Only when researchers know *with precision* what to expect from an experiment can they recognize that something has gone wrong.
4. Consequently, *anomaly appears only against the background provided by the paradigm* (65).
    a. The more precise and far-reaching the paradigm, the more sensitive it is to detecting an anomaly and inducing change.
    b. By resisting change, a paradigm guarantees that anomalies that lead to paradigm change will penetrate existing knowledge to the core.

Chapter VII - Crisis and the Emergence of Scientific Theories.

This chapter traces paradigm changes that result from the *invention* of new theories brought about by the failure of existing theory to solve the problems defined by that theory. This failure is acknowledged as a *crisis* by the scientific community.

A. As is the case with discovery, a change in an existing theory that results in the *invention* of a new theory is also brought about by the awareness of anomaly.

B. The emergence of a new theory is generated by the persistent failure of the puzzles of normal science to be solved as they should. *Failure of existing rules* *is the prelude to a search for new ones* (68). These failures can be brought about by

1. observed *discrepancies* between theory and fact—this is the "core of the crisis" (69).
2. changes in social/cultural climates (knowledge/beliefs are socially constructed?).
    a. There are strong historical precedents for this: Copernicus, Freud, behaviorism? constructivism?
    b. Science is often "ridden by dogma" (75)—what may be the effect on science (or art) by an atmosphere of political correctness?
3. scholarly criticism of existing theory.

C. Such failures are generally long recognized, which is why crises are seldom surprising.
    1. Neither problems nor puzzles yield often to the first attack (75).
    2. Recall that paradigm and theory resist change and are extremely resilient.

D. *Philosophers of science have repeatedly demonstrated that more than one theoretical construction can always be placed upon a given collection of data* (76).
    1. In early stages of a paradigm, such theoretical alternatives are easily invented.
    2. Once a paradigm is entrenched (and the tools of the paradigm prove useful to solve the problems the paradigm defines), theoretical alternatives are strongly resisted.
        a. *As in manufacture so in science—retooling is an extravagance to be reserved for the occasion that demands it* (76).
        b. Crises provide the opportunity to retool.

Chapter VIII - The Response to Crisis.

The awareness and acknowledgment that a crisis exists loosens theoretical stereotypes and provides the incremental data necessary for a fundamental paradigm shift. In this critical chapter, Kuhn discusses how scientists respond to the anomaly in fit between theory and nature so that a transition to crisis and to *extraordinary science* begins, and he foreshadows how the process of paradigm change takes place.

A. Normal science does and must continually strive to bring theory and fact into closer agreement.

B. The recognition and acknowledgment of anomalies result in *crises* that are a necessary precondition for the emergence of novel theories and for paradigm change.
    1. Crisis is the *essential tension* implicit in scientific research (79).
    2. There is no such thing as research without *counterinstances*, i.e., anomaly.
        a. These counterinstances create tension and crisis.
        b. Crisis is always implicit in research because every problem that normal science sees as a puzzle can be seen, from another viewpoint, as a counterinstance and thus as a source of crisis (79).

C. In responding to these crises, scientists generally do *not* renounce the paradigm that has led them into crisis.
    1. They may lose faith and consider alternatives, but

2. they generally do not treat anomalies as counterinstances of expected outcomes.
3. They devise numerous articulations and *ad hoc* modifications of their theory in order to eliminate any apparent conflict.
4. Some, unable to tolerate the crisis (and thus unable to live *in a world out of joint*), leave the profession.
5. As a rule, *persistent and recognized anomaly does not induce crisis* (81).
6. Failure to achieve the expected solution to a puzzle discredits only the scientist and not the theory ("it is a poor carpenter who blames his tools").
7. Science is taught to ensure confirmation-theory.
8. Science students accept theories on the authority of teacher and text—what alternative do they have, or what competence?

D. To evoke a crisis, an anomaly must usually be more than just an anomaly.
   1. After all, there are always anomalies (counterinstances).
   2. Scientists who paused and examined every anomaly would not get much accomplished.
   3. An anomaly can call into question fundamental generalizations of the paradigm.
   4. An anomaly without apparent fundamental import may also evoke crisis if the applications that it inhibits have a particular practical importance.
   5. An anomaly must come to be seen as more than just another puzzle of normal science.
   6. In the face of efforts outlined in C above, the anomaly must continue to resist.

E. All crises begin with the *blurring of a paradigm* and the consequent loosening of the rules for normal research. As this process develops,
   1. the anomaly comes to be more generally recognized as such.
   2. more attention is devoted to it by more of the field's eminent authorities.
   3. the field begins to look quite different.
   4. scientists express explicit discontent.
   5. competing articulations of the paradigm proliferate.
   6. scholars view a resolution as *the* subject matter of their discipline. To this end, they
      a. first isolate the anomaly more precisely and give it structure.
      b. push the rules of normal science harder than ever to see, in the area of difficulty, just where and how far they can be made to work.
      c. seek for ways of magnifying the breakdown.
      d. generate speculative theories.
         i. If successful, one theory may disclose the road to a new paradigm.
         ii. If unsuccessful, the theories can be surrendered with relative ease.
      e. may turn to philosophical analysis and debate over fundamentals as a device for unlocking the riddles of their field.
   7. crisis often proliferates new discoveries.

F. All crises close in one of three ways.
   1. Normal science proves able to handle the crisis-provoking problem and all returns to "normal."

2. The problem resists and is labeled, but it is perceived as resulting from the field's failure to possess the necessary tools with which to solve it, and so scientists set it aside for a future generation with more developed tools.
3. A new candidate for paradigm emerges, and a battle over its acceptance ensues (84)—these are the *paradigm wars*.
    a. Once it has achieved the status of paradigm, a paradigm is declared invalid *only if an alternate candidate is available to take its plac*e (77).
        i. Because there is no such thing as research in the absence of a paradigm, to reject one paradigm without simultaneously substituting another is to reject science itself.
        ii. To declare a paradigm invalid will require more than the falsification of the paradigm by direct comparison with nature.
        iii. The judgment leading to this decision involves the comparison of the existing paradigm with nature *and* with the alternate candidate.
    b. Transition from a paradigm in crisis to a new one from which a new tradition of normal science can emerge is not a cumulative process. It is a *reconstruction of the field from new fundamentals* (85). This reconstruction
        i. changes some of the field's foundational theoretical generalizations.
        ii. changes methods and applications.
        iii. alters the rules.
    c. How do new paradigms finally *emerge*?
        i. Some emerge all at once, sometimes in the middle of the night, in the mind of a man deeply immersed in crisis.
        ii. Those who achieve fundamental inventions of a new paradigm have generally been either very young or very new to the field whose paradigm they changed.
        iii. Much of this process is *inscrutable and may be permanently so*.

G. When a transition from former to alternate paradigm is complete, the profession changes its view of the field, its methods, and its goals.
    1. This reorientation has been described as "handling the same bundle of data as before, but placing them in a new system of relations with one another by giving them a different framework" or "picking up the other end of the stick" (85).
    2. Some describe the reorientation as a *gestalt shift.*
    3. Kuhn argues that the gestalt metaphor is misleading: *"Scientists do not see something as something else; instead, they simply see it"* (85).

H. The emergence of a new paradigm/theory breaks with one tradition of scientific practice that is perceived to have gone badly astray and introduces a new one conducted under different rules and within a different *universe of discourse.*

I. The transition to a new paradigm is *scientific revolution*—and this is the transition from normal to extraordinary research.

Chapter IX - The Nature and Necessity of Scientific Revolutions.

Why should a paradigm change be called a revolution? What are the functions of scientific revolutions in the development of science?

A. A scientific revolution is *a noncumulative developmental episode in which an older paradigm is replaced in whole or in part by an incompatible new one* (92).
B. A scientific revolution that results in paradigm change is analogous to a political revolution. [Note the striking similarity between the characteristics outlined below regarding the process of political revolution and those earlier outlined regarding the process of scientific revolution]
    1. Political revolutions begin with a growing sense by members of the community that existing institutions have ceased adequately to meet the problems posed by an environment that they have in part created—anomaly and crisis.
    2. The dissatisfaction with existing institutions is generally restricted to a segment of the political community.
    3. Political revolutions aim to change political institutions in ways that those institutions themselves prohibit.
    4. During a revolution's interim, society is not fully governed by institutions at all.
    5. In increasing numbers, individuals become increasingly estranged from political life and behave more and more eccentrically within it.
    6. As crisis deepens, individuals commit themselves to some concrete proposal for the reconstruction of society in a new institutional framework.
    7. Competing camps and parties form.
        a. One camp seeks to defend the old institutional constellation.
        b. One (or more) camps seek to institute a new political order.
    8. As polarization occurs, *political recourse fails.*
    9. Parties to a revolutionary conflict finally resort to the techniques of mass persuasion.
C. Like the choice between competing political institutions, that between competing paradigms proves to be a choice between *fundamentally incompatible* modes of community life. *Paradigmatic differences cannot be reconciled.*
    1. The evaluative procedures characteristic of normal science do not work, for these depend on a particular paradigm for their existence.
    2. When paradigms enter into a debate about fundamental questions and paradigm choice, each group uses its own paradigm to argue in that paradigm's defense—the result is a circularity and inability to share a universe of discourse.
    3. Fundamental paradigmatic assumptions are philosophically incompatible.
    4. Ultimately, scientific revolutions are affected by
        a. the impact of nature and of logic.
        b. techniques of persuasive argumentation (a struggle between stories?).

5. A successful new paradigm/theory permits predictions that are *different* from those derived from its predecessor (98).
    a. That difference could not occur if the two were logically compatible.
    b. In the process of being assimilated, the second must displace the first.

D. Consequently*, the assimilation of either a new sort of phenomenon or a new scientific theory must demand the rejection of an older paradigm* (95).
    1. If this were not so, scientific development would be genuinely cumulative (the view of *science-as-cumulation* or *logical inclusiveness*—see Chapter X).
    2. Recall that cumulative acquisition of unanticipated novelties proves to be an almost nonexistent exception to the rule of scientific development—c*umulative acquisition of novelty is not only rare in fact but improbable in principle* (96).
    3. Normal research *is* cumulative, but not scientific revolution.
    4. *New paradigms arise with destructive changes in beliefs about nature* (98).
    5. Kuhn observes that his view is not the prevalent view. The prevalent view maintains that a new paradigm derives from, or is a cumulative addition to, the supplanted paradigm. [Note: This was the case in the late 1950s and early 1960s, when the book was published, but it is not the case today. As Kuhn points out, logical positivists were carrying the day then, but *Structure* proved revolutionary itself, and Kuhn's view is reasonably influential these days. Many would argue that Kuhn's view is now the prevalent view.] Objections to Kuhn's view include that
        a. only the extravagant claims of the old paradigm are contested.
        b. purged of these merely human extravagances, many old paradigms have never been and can never be challenged (e.g., Newtonian physics, behaviorism? psychoanalytic theory? logical positivism?).
        c. a scientist can reasonably work within the framework of more than one paradigm (and so *eclecticism* and, to some extent, *relativism* rear their heads).
    6. Kuhn refutes this *logical positivist* view, arguing that
        a. the logical positivist view makes any theory ever used by a significant group of competent scientists immune to attack.
        b. to save paradigms/theories in this way, their range of application must be restricted to those phenomena and to that precision of observation with which the experimental evidence in hand already deals.
        c. the rejection of a paradigm requires the rejection of its fundamental assumptions and of its rules for doing science—they are incompatible with those of the new paradigm.
        d. if the fundamental assumptions of old and new paradigm were not incompatible, novelty could always be explained within the framework of the old paradigm and crisis can always be avoided.
        e. revolution is not cumulation; revolution is transformation.
        f. the price of significant scientific advance is a commitment that runs the risk of being wrong.

   g. without commitment to a paradigm there can be no normal science.
   h. the need to change the meaning of established and familiar concepts is central to the revolutionary impact of a new paradigm.
   i. the differences between successive paradigms are both necessary and irreconcilable. Why?
      i. because successive paradigms tell us different things about the population of the universe and about that population's behavior.
      ii. because paradigms are the source of the methods, problem-field, and standards of solution accepted by any *mature* scientific community at any given time.
   j. *the reception of a new paradigm often necessitates a redefinition of the corresponding science* (103).
      i. Old problems are relegated to other sciences or declared unscientific.
      ii. Problems previously nonexistent or trivial may, with a new paradigm, become the very archetypes of significant scientific achievement.
7. Consequently, *"the normal-scientific tradition that emerges from a scientific revolution is not only incompatible but often actually incommensurable with that which has gone before"* (103).

E. The case for cumulative development of *science's problems and standards* is even harder to make than the case for the cumulative development of paradigms/theories.
   1. Standards are neither raised nor do they decline; standards simply *change* as a result of the adoption of the new paradigm.
   2. Paradigms act as *maps* that chart the direction of problems and methods through which problems may be solved.
   3. Because nature is too complex and varied to be explored at random, the map is an essential guide to the process of normal science.
   4. In learning a paradigm, the scientist acquires theory, methods, and standards together, usually in an inextricable mixture.
   5. Therefore, *when paradigms change, there are usually significant shifts in the criteria determining the legitimacy both of problems and of proposed solutions* (109).

F. *To the extent that two scientific schools disagree about what is a problem and what a solution, they will inevitably talk through each other when debating the relative merits of their respective paradigms* (109).
   1. In the *circular argument* that results from this conversation, each paradigm will
      a. satisfy more or less the criteria that it dictates for itself, and
      b. fall short of a few of those dictated by its opponent.
   2. Since no two paradigms leave all the same problems unsolved, paradigm debates always involve the question: Which problems is it more significant to have solved?
   3. In the final analysis, this involves a question of *values* that lie outside of normal science altogether—it is this recourse to external criteria that

most obviously makes paradigm debates revolutionary (see B-8/9 above).

Chapter X - Revolutions as Changes of World View.

When paradigms change, the world itself changes with them. How do the beliefs and conceptions of scientists change as the result of a paradigm shift? Are theories simply man-made interpretations of given data?

A. During scientific revolutions, scientists see new and different things when looking with familiar instruments in places they have looked before.
    1. Familiar objects are seen in a different light and joined by unfamiliar ones as well.
    2. Scientists *see the world* of their research-engagement differently.
    3. Scientists see new things when looking at old objects.
    4. In a sense, after a revolution, scientists are responding to a different world.

B. This difference in view resembles a *gestalt shift, a perceptual transformation*—"what were ducks in the scientist's world before the revolution are rabbits afterward." But *caution*—there are important differences.
    1. Something like a paradigm is a *prerequisite* to perception itself (recall G. H. Mead's concept of a *predisposition*, or the dictum *it takes a meaning to catch a meaning).*
    2. What people see depends both on what they look at and on what their previous visual-conceptual experience has *taught* them to see.
    3. Individuals know when a gestalt shift has taken place because they are aware of the shift—they can even manipulate it mentally.
    4. In a gestalt switch, alternate perceptions are equally "true" (valid, reasonable, real).
    5. Because there are *external standards* with respect to which switch of vision can be demonstrated, conclusions about alternate perceptual possibilities can be drawn.
        a. But scientists have no such external standards
        b. Scientists have no recourse to a higher authority that determines when a switch in vision has taken place.
    6. As a consequence, in the sciences, if perceptual switches accompany paradigm changes, scientists cannot attest to these changes directly.
    7. A gestalt switch: "I used to see a planet, but now I see a satellite." (This leaves open the possibility that the earlier perception was once and may still be correct).
    8. A paradigm shift: " I used to see a planet, but I was wrong."
    9. It is true, however, that anomalies and crises "are terminated by a relatively sudden and unstructured event like the gestalt switch" (122).

C. Why does a shift in view occur?
    1. Genius? Flashes of intuition? Sure.
    2. Paradigm-induced gestalt shifts? Perhaps, but see limitations above.
    3. Because different scientists *interpret* their observations differently? No.
        a. Observations (data) are themselves nearly always different.

    b. Because observations are conducted (data collected) within a paradigmatic framework, the interpretive enterprise can only articulate a paradigm, not correct it.
  4. Because of factors embedded in the nature of human perception and retinal impression? No doubt, but our knowledge is simply not yet advanced enough on this matter.
  5. Changes in definitional conventions? No.
  6. Because the existing paradigm fails to fit. Always.
  7. Because of a change in the relation between the scientist's manipulations and the paradigm or between the manipulations and their concrete results? You bet.
- D. It is hard to make nature fit a paradigm.

Chapter XI - The Invisibility of Revolutions.

Because paradigm shifts are generally viewed not as revolutions but as additions to scientific knowledge, and because the history of the field is represented in the new textbooks that accompany a new paradigm, a scientific revolution seems invisible.

- A. An increasing reliance on textbooks is an invariable concomitant of the emergence of a first paradigm in any field of science (136).
- B. The image of creative scientific activity is largely created by a field's textbooks.
  1. Textbooks are the pedagogic vehicles for the perpetuation of normal science.
  2. These texts become the authoritative source of the history of science.
  3. Both the layman's and the practitioner's knowledge of science is based on textbooks.
- C. A field's texts must be rewritten in the aftermath of a scientific revolution.
  1. Once rewritten, they inevitably disguise no only the role but the existence and significance of the revolutions that produced them.
  2. The resulting textbooks truncate the scientist's sense of his discipline's history and supply a substitute for what they eliminate.
     a. More often than not, they contain very little history at all (Whitehead: "A science that hesitates to forget its founders is lost.")
     b. In the rewrite, earlier scientists are represented as having worked on the same set of fixed problems and in accordance with the same set of fixed canons that the most recent revolution and method has made seem scientific.
     c. Why dignify what science's best and most persistent efforts have made it possible to discard?
- D. The historical *reconstruction* of previous paradigms and theorists in scientific textbooks make the history of science look linear or cumulative, a tendency that even affects scientists looking back at their own research (139).
  1. These *misconstructions* render revolutions invisible.
  2. They also work to deny revolutions as a function.
- E. Science textbooks present the *inaccurate view* that science has reached its present state by a series of individual discoveries and inventions that, when gathered together, constitute the modern body of technical knowledge—*the addition of bricks to a building*.

1. This *piecemeal-discovered* facts approach of a textbook presentation illustrates the pattern of historical mistakes that misleads both students and laymen about the nature of the scientific enterprise.
2. *More than any other single aspect of science, that pedagogic form [the textbook] has determined our image of the nature of science and of the role of discovery and invention in its advance.*

Chapter XII - The Resolution of Revolutions.

How do the proponents of a competing paradigm convert the entire profession or the relevant subgroup to their way of seeing science and the world? What causes a group to abandon one tradition of normal research in favor of another? What is the process by which a new candidate for paradigm replaces its predecessor?

A. Scientific revolutions come about when one paradigm displaces another after a period of paradigm-testing that occurs
    1. only after persistent failure to solve a noteworthy puzzle has given rise to crisis.
    2. as part of the competition between two rival paradigms for the allegiance of the scientific community.
B. The process of paradigm-testing parallels two popular philosophical theories about the *verification* of scientific theories.
    1. Theory-testing through *probabilistic* verification.
        a. Comparison of the ability of different theories to explain the evidence at hand.
        b. This process is analogous to natural selection: one theory becomes the most viable among the actual alternatives in a particular historical situation.
    2. Theory-testing through *falsification* (Karl Popper).
        a. A theory must be rejected when outcomes predicted by the theory are negative.
        b. The role attributed to falsification is similar to the one that Kuhn assigns to anomalous experiences.
        c. Kuhn doubts that falsifying experiences exist.
            i. No theory ever solves all the puzzles with which it is confronted at a given time.
            ii. It is the incompleteness and imperfection of the existing data-theory fit that define the puzzles that characterize normal science.
            iii. If any and every failure to fit were ground for theory rejection, all theories ought to be rejected at all times.
            iv. If only severe failure to fit justifies theory rejection, then theory-testing through falsification would require some criterion of *improbability* or of *degree of falsification*—thereby requiring recourse to 1 above.
C. It makes little sense to suggest that verification is establishing the agreement of fact with theory.
    1. All historically significant theories have agreed with the facts, but only more or less.

2. It makes better sense to ask which of two competing theories fits the facts *better*.
3. Recall that scientists in paradigmatic disputes tend to talk through each other.
4. Competition between paradigms is not the sort of battle that can be resolved by proofs.
5. Since new paradigms are born from old ones, they incorporate much of the vocabulary and apparatus that the traditional paradigm had previously employed, though these elements are employed in different ways.
6. Moreover, *proponents of competing paradigms practice their trade in different worlds*—the two groups *see* different things (i.e., the facts are differently viewed).
7. Like a gestalt switch, verification occurs all at once or not at all (150).

D. Although a generation is sometimes required to effect a paradigm change, scientific communities have again and again been converted to new paradigms.
    1. Max Planck: *A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grow up that is familiar with it.*
    2. But Kuhn argues that Planck's famous remark overstates the case.
        a. Neither proof nor error is at issue.
        b. The transfer of allegiance from paradigm to paradigm is a conversion experience that cannot be forced.
        c. Proponents of a paradigm devote their lives and careers to the paradigm.
        d. Lifelong resistance is not a violation of scientific standards but an index to the nature of scientific research itself.
        e. The source of the resistance is the assurance that
            i. the older paradigm will ultimately solve all its problems.
            ii. nature can be shoved into the box the paradigm provides.
        f. Actually, that same assurance is what makes normal science possible.
        g. Some scientists, particularly the older and more experienced ones, may resist indefinitely, but most can be reached in one way or another.
    3. *Conversions occur not despite the fact that scientists are human but because they are.*
    4. How are scientists converted? How is conversion induced and how resisted?
        a. Individual scientists embrace a new paradigm for all sorts of reasons and usually for several at once.
            i. idiosyncracy of autobiography and personality?
            ii. nationality or prior reputation of innovator and his teachers?
        b. The focus of these questions should not be on the individual scientist but with the sort of community that always sooner or later re-forms as a single group (this will be dealt with in Chapter XIII).

        c. The community recognizes that a new paradigm displays a quantitative precision strikingly better than its older competitor.
            i. A claim that a paradigm solves the crisis-provoking problem is rarely sufficient by itself.
            ii. Persuasive arguments can be developed if the new paradigm permits the prediction of phenomena *that had been entirely unsuspected while the old paradigm prevailed*.
        d. Rather than a single group conversion, what occurs is an increasing shift in the distribution of professional allegiances (158).
        e. But paradigm debates are not about relative problem-solving ability. Rather *the issue is which paradigm should in the future guide research on problems many of which neither competitor can yet claim to resolve completely* (157).
            i. A decision between alternate ways of practicing science is called for.
            ii. A decision is based on future promise rather than on past achievement.
            iii. A scientist must have *faith* that the new paradigm will succeed with the many large problems that confront it.
                1. There must be a *basis* for this faith in the candidate chosen.
                2. Sometimes this faith is based on personal and inarticulate aesthetic considerations.
            iv. This is not to suggest that new paradigms triumph ultimately through some mystical aesthetic.
        f. The new paradigm appeals to the individual's sense of the appropriate or the aesthetic—the new paradigm is said to be *neater*, *more suitable*, *simpler*, or more *elegant* (155).

E. What is the process by which a new candidate for paradigm replaces its predecessor?
    1. At the start, a new candidate for paradigm may have few supporters (and the motives of the supporters may be suspect).
    2. If the supporters are competent, they will
        a. improve the paradigm,
        b. explore its possibilities,
        c. and show what it would be like to belong to the community guided by it.
    3. For the paradigm destined to win, the number and strength of the persuasive arguments in its favor will increase.
    4. As more and more scientists are converted, exploration increases.
    5. The number of experiments, instruments, articles, and books based on the paradigm will multiply.
    6. More scientists, convinced of the new view's fruitfulness, will adopt the new mode of practicing normal science (until only a few elderly hold-outs will remain).
        a. And we cannot say that they are (were) wrong.

   b. Perhaps the scientist who continues to resist after the whole profession has been converted has *ipso facto* ceased to be a scientist.

Chapter XIII - Progress Through Revolutions.

In the face of the arguments previously made, why does science *progress*, how does it progress, and what is the nature of its progress?

A. Perhaps *progress* is inherent in the definition of science.
   1. To a very great extent, the term *science* is reserved for fields that do progress in obvious ways.
   2. This issue is of particular import to the *social* sciences.
      a. Is a social science a science because it *defines itself* as a science in terms of possessing certain characteristics and aims to make progress?
      b. Questions about whether a field or discipline is a science *will cease to be a source of concern not when a definition is found, but when the groups that now doubt their own status achieve consensus about their past and present accomplishments* (161).
         i. Do economists worry less than educators about whether their field is a science because economists know what a science is? Or is it economics about which they agree?
         ii. Why do not natural scientists or artists worry about the definition of the term?
   3. *We tend to see as a science any field in which progress is marked* (162).
B. Does a field make progress because it is a science, or is it a science because it makes progress?
C. Normal science progresses because the enterprise shares certain salient characteristics,
   1. Members of a mature scientific community work from a single paradigm or from a closely related set.
   2. Very rarely do different scientific communities investigate the same problems.
D. The result of successful creative work *is* progress (162).
   1. *No creative school recognizes a category of work that is, on the one hand, a creative success, but is not, on the other, an addition to the collective achievement of the group*.
   2. Even if we argue that a field does not make progress, that does not mean that an individual school/discipline within that field does not.
   3. The man who argues that philosophy has made no progress emphasizes that there are still Aristotelians, not that Aristotelianism has failed to progress.
E. It is only during periods of normal science that progress seems both obvious and assured.
   1. In part, this progress is in the eye of the beholder.
   2. The absence of competing paradigms that question each other's aims and standards makes the progress of a normal-scientific community far easier to see.

3. The acceptance of a paradigm frees the community from the need to constantly re-examine its first principles and foundational assumptions.
4. Members of the community can concentrate on the subtlest and most esoteric of the phenomena that concern it.
5. There are no other professional communities in which individual creative work is so exclusively addressed to and evaluated by other members of the profession.
    a. Other professions are more concerned with lay approbation than are scientists.
    b. Because scientists work only for an audience of colleagues, an audience that shares values and beliefs, a single set of standards can be taken for granted.
    c. This insulation of the scientist from society permits the individual scientist to concentrate attention on problems that she has a good reason to believe she will be able to solve.
6. Unlike in other disciplines, the scientist need not select problems because they urgently need solution and without regard for the tools available to solve them [note the important contrast here between natural scientists and social scientists].
    a. The social scientists tend to defend their choice of a research problem chiefly in terms of the social importance of achieving a solution.
    b. Which group would one then expect to solve problems at a more rapid rate?
7. The effects of insulation are intensified by the nature of the scientific community's educational initiation.
    a. The education of a social scientist consists in large part of
        i. reading original sources.
        ii. being made aware of the variety of problems that the members of his future group have, in the course of time, attempted to solve, and the paradigms that have resulted from these attempts.
        iii. facing competing and incommensurable solutions to these problems.
        iv. evaluating the solutions to the problems presented.
        v. selecting among competing existing paradigms.
    b. In the education of a natural scientist
        i. textbooks (as described earlier) are used until graduate school.
        ii. textbooks are systematically substituted for the creative scientific literature that made them possible.
        iii. *classics* are seldom read, and they are viewed as antiquated oddities.
8. The educational initiation of scientists is immensely effective.
9. The education of scientists prepares them for *the generation through normal science of significant crises* (167).

F. In its normal state, a scientific community is an immensely efficient instrument for solving the problems or puzzles that its paradigms define—progress is the result of solving these problems.

G. Progress is also a salient feature of extraordinary science—of science during a revolution.
    1. Revolutions close with total victory for one of the two opposing camps.
    2. When it repudiates a paradigm, a scientific community simultaneously renounces most of the books and articles in which that paradigm had been embodied.
    3. The community acknowledges this as progress.
    4. In a sense, it may appear that *the member of a mature scientific community is the victim of a history rewritten by the powers that be* (167).
        a. But recall that the power to select between paradigms resides in the members of the community.
        b. The process of scientific revolution is in large part a democratic process.

H. And what are the characteristics of these scientific communities?
    1. The scientist must be concerned to solve problems about the behavior of nature.
    2. Although the concerns may be global, the problems must be problems of detail
    3. The solutions to problems that satisfy a scientist must satisfy the community.
    4. No appeals to heads of state or to the populace at large in matters scientific.
    5. Members of the community are recognized and are the exclusive arbiters of professional achievement.
        a. Because of their shared training and experience, members of the community are seen as the sole possessors of the rules of the game.
        b. To doubt that they share some basis for evaluation would be to admit the existence of incompatible standards of scientific achievement.
    6. The community must see paradigm change as progress—as we have seen, this perception is, in important respects, self-fulfilling (169).
    7. Discomfort with a paradigm takes place only when nature itself first undermines professional security by making prior achievements seem problematic.
    8. The community embraces a new paradigm when
        a. the new candidate is seen to resolve some outstanding and generally recognized problem that can be met in no other way.
        b. the new paradigm promises to preserve a relatively large part of the concrete problem-solving ability that has accrued to science through its predecessors.

I. Though science surely grows in depth, it may not grow in breadth as well. When it does,
    1. this is manifest through the proliferation of specialties,
    2. not in the scope of any single specialty alone.

J. *We may have to relinquish the notion, explicit or implicit, that changes of paradigm carry scientists and those who learn from them closer and closer to the* ***truth*** (171).

1. The developmental process described by Kuhn is a process of evolution from primitive beginnings—a process whose successive stages are characterized by an increasingly detailed and refined understanding of nature.
2. This is not a process of evolution *toward* anything.
3. Important questions arise.
    a. Must there be a goal set by nature in advance?
    b. Does it really help to imagine that there is some one full, objective, true account of nature?
    c. Is the proper measure of scientific achievement the extent to which it brings us closer to an ultimate goal?
4. The analogy that relates the evolution of organisms to the evolution of scientific ideas "is nearly perfect" (172).
    a. The resolution of revolutions is the selection by conflict within the scientific community of the fittest way to practice future science.
    b. The net result of a sequence of such revolutionary selections, separated by period of normal research, is the wonderfully adapted set of instruments we call modern scientific knowledge.
    c. Successive stages in that developmental process are marked by an increase in articulation and specialization.
    d. The process occurs without benefit of a set goal and without benefit of any permanent fixed scientific truth.
5. *What must the world be like in order that man may know it?*

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The Structure of Scientific Revolutions

by Thomas S. Kuhn

A Synopsis from the original by Professor Frank Pajares
From the Philosopher's Web Magazine

I Introduction

A scientific community cannot practice its trade without some set of received beliefs. These beliefs form the foundation of the "educational initiation that prepares and licenses the student for professional practice". The nature of the "rigorous and rigid" preparation helps ensure that the received beliefs are firmly fixed in the student's mind. Scientists take great pains to defend the assumption that scientists know what the world is like...To this end, "normal science" will often suppress novelties which undermine its foundations. Research is therefore not about discovering the unknown, but rather "a strenuous and devoted attempt to force nature into the conceptual boxes supplied by professional education".

A shift in professional commitments to shared assumptions takes place when an anomaly undermines the basic tenets of the current scientific practice These shifts are what Kuhn describes as scientific revolutions - "the tradition-shattering complements to the tradition-bound activity of normal science" New assumptions –"paradigms" - require the reconstruction of prior assumptions and the re-evaluation of prior facts. This is difficult and time consuming. It is also strongly resisted by the established community.

II The Route to Normal Science

So how are paradigms created and what do they contribute to scientific inquiry?

Normal science "means research firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice". These achievements must be sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity and sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners (and their students) to resolve. These achievements can be called paradigms. Students study these paradigms in order to become members of the particular scientific community in which they will later practice.

Because the student largely learns from and is mentored by researchers "who learned the bases of their field from the same concrete models" there is seldom disagreement over fundamentals. Men whose research is based on shared paradigms are committed to the same rules and standards for scientific practice. A shared commitment to a paradigm ensures that its practitioners engage in the paradigmatic observations that its own paradigm can do most to explain. Paradigms help scientific communities to bound their discipline in that they help the scientist to create avenues of inquiry, formulate questions, select methods with which to examine questions, define areas of relevance. and establish or create meaning. A paradigm is essential to scientific inquiry - "no natural history can be interpreted in the absence of at least some implicit body of intertwined theoretical and methodological belief that permits selection, evaluation, and criticism".

How are paradigms created, and how do scientific revolutions take place? Inquiry begins with a random collection of "mere facts" (although, often, a body of beliefs is already implicit in the collection). During these early stages of inquiry, different researchers confronting the same phenomena describe and interpret them in different ways. In time, these descriptions and interpretations entirely disappear. A pre-paradigmatic school appears. Such a school often emphasises a special part of the collection of facts. Often, these schools vie for pre-eminence.

From the competition of these pre-paradigmatic schools, one paradigm emerges - "To be accepted as a paradigm, a theory must seem better than its competitors, but it need not, and in fact never does, explain all the facts with which it can be confronted", thus making research possible. As a paradigm grows in strength and in the number of advocates, the other pre-paradigmatic schools or the previous paradigm fade.

A paradigm transforms a group into a profession or, at least, a discipline. And from this follow the formation of specialised journals, foundation of professional bodies and a claim to a special place in academe. There is a promulgation of scholarly articles intended for and "addressed only to professional colleagues, [those] whose knowledge of a shared paradigm can be assumed and who prove to be the only ones able to read the papers addressed to them".

III - The Nature of Normal Science.

If a paradigm consists of basic and incontrovertible assumptions about the nature of the discipline, what questions are left to ask?

When they first appear, paradigms are limited in scope and in precision. But more successful does not mean completely successful with a single problem or notably successful with any large number. Initially, a paradigm offers the promise of success. Normal science consists in the actualisation of that promise. This is achieved by extending the knowledge of those facts that the paradigm displays as particularly revealing, increasing the extent of the match between those facts and the paradigm's predictions, and further articulation of the paradigm itself.

In other words, there is a good deal of mopping-up to be done. Mop-up operations are what engage most scientists throughout their careers. Mopping-up is what normal science is all about! This paradigm-based research is "an attempt to force nature into the pre-formed and relatively inflexible box that the paradigm supplies". No effort is made to call forth new sorts of phenomena, no effort to discover anomalies. When anomalies pop up, they are usually discarded or ignored. Anomalies are usually not even noticed and no effort is made to invent a new theory (and there’s no tolerance for those who try). Those restrictions, born from confidence in a paradigm, turn out to be essential to the development of science. By focusing attention on a small range of relatively esoteric problems, the paradigm forces scientists to investigate some part of nature in a detail and depth that would otherwise be unimaginable" and, when the paradigm ceases to function properly, scientists begin to behave differently and the nature of their research problems changes.

IV - Normal Science as Puzzle-solving.

Doing research is essentially like solving a puzzle. Puzzles have rules. Puzzles generally have predetermined solutions.

A striking feature of doing research is that the aim is to discover what is known in advance. This in spite of the fact that the range of anticipated results is small compared to the possible results. When the outcome of a research project does not fall into this anticipated result range, it is generally considered a failure.

So why do research? Results add to the scope and precision with which a paradigm can be applied. The way to obtain the results usually remains very much in doubt - this is the challenge of the puzzle. Solving the puzzle can be fun, and expert puzzle-solvers make a very nice living. To classify as a puzzle (as a genuine research question), a problem must be characterised by more than the assured solution, but at the same time solutions should be consistent with paradigmatic assumptions.

Despite the fact that novelty is not sought and that accepted belief is generally not challenged, the scientific enterprise can and does bring about unexpected results.

V - The Priority of Paradigms.

The paradigms of a mature scientific community can be determined with relative ease. The "rules" used by scientists who share a paradigm are not so easily determined. Some reasons for this are that scientists can disagree on the interpretation of a paradigm. The existence of a paradigm need not imply that any full set of rules exist. Also, scientists are often guided by tacit knowledge - knowledge acquired through practice and that cannot be articulated explicitly. Further, the attributes shared by a paradigm are not always readily apparent.

Paradigms can determine normal science without the intervention of discoverable rules or shared assumptions. In part, this is because it is very difficult to discover the rules that guide particular normal-science traditions. Scientists never learn concepts, laws, and theories in the abstract and by themselves. They generally learn these with and through their applications. New theory is taught in tandem with its application to a concrete range of phenomena.

Sub-specialties are differently educated and focus on different applications for their research findings. A paradigm can determine several traditions of normal science that overlap without being coextensive. Consequently, changes in a paradigm affect different sub-specialties differently. "A revolution produced within one of these traditions will not necessarily extend to the others as well".

When scientists disagree about whether the fundamental problems of their field have been solved, the search for rules gains a function that it does not ordinarily possess .

VI - Anomaly and the Emergence of Scientific Discoveries.

If normal science is so rigid and if scientific communities are so close-knit, how can a paradigm change take place? Paradigm changes can result from discovery brought about by encounters with anomaly.

Normal science does not aim at novelties of fact or theory and, when successful, finds none. Nonetheless, new and unsuspected phenomena are repeatedly uncovered by scientific research, and radical new theories have again and again been invented by scientists . Fundamental novelties of fact and theory bring about paradigm change. So how does paradigm change come about? There are two ways: through discovery - novelty of fact - or by invention – novelty of theory. Discovery begins with the awareness of anomaly - the recognition that nature has violated the paradigm-induced expectations that govern normal science. The area of the anomaly is then explored. The paradigm change is complete when the paradigm has been adjusted so that the anomalous become the expected. The result is that the scientist is able "to see nature in a different way".. How paradigms change as a result of invention is discussed in greater detail in the following chapter.

Although normal science is a pursuit not directed to novelties and tending at first to suppress them, it is nonetheless very effective in causing them to arise. Why? An initial paradigm accounts quite successfully for most of the observations and experiments readily accessible to that science's practitioners. Research results in the construction of elaborate equipment, development of an esoteric and shared vocabulary, refinement of concepts that increasingly lessens their resemblance to their usual common-sense prototypes. This professionalisation leads to immense restriction of the scientist's vision, rigid science, resistance to paradigm change, and a detail of information and precision of the observation-theory match that can be achieved in no other way. New and refined methods and instruments result in greater precision and understanding of the paradigm. Only when researchers know with precision what to expect from an experiment can they recognise that something has gone wrong.

Consequently, anomaly appears only against the background provided by the paradigm . The more precise and far-reaching the paradigm, the more sensitive it is to detecting an anomaly and inducing change. By resisting change, a paradigm guarantees that anomalies that lead to paradigm change will penetrate existing knowledge to the core.

VII - Crisis and the Emergence of Scientific Theories.

As is the case with discovery, a change in an existing theory that results in the invention of a new theory is also brought about by the awareness of anomaly. The emergence of a new theory is generated by the persistent failure of the puzzles of normal science to be solved as they should. Failure of existing rules is the prelude to a search for new ones . These failures can be brought about by observed discrepancies between theory and fact or changes in social/cultural climates Such failures are generally long recognised, which is why crises are seldom surprising. Neither problems nor puzzles yield often to the first attack . Recall that paradigm and theory resist change and are extremely resilient. Philosophers of science have repeatedly demonstrated that more than one theoretical construction can always be placed upon a given collection of data . In early stages of a paradigm, such theoretical alternatives are easily invented. Once a paradigm is entrenched (and the tools of the paradigm prove useful to solve the problems the paradigm defines), theoretical alternatives are strongly resisted. As in manufacture so in science--retooling is an extravagance to be reserved for the occasion that demands it . Crises provide the opportunity to retool.

VIII - The Response to Crisis.

The awareness and acknowledgement that a crisis exists loosens theoretical stereotypes and provides the incremental data necessary for a fundamental paradigm shift. Normal science does and must continually strive to bring theory and fact into closer agreement. The recognition and acknowledgement of anomalies result in crises that are a necessary precondition for the emergence of novel theories and for paradigm change. Crisis is the essential tension implicit in scientific research. There is no such thing as research without counterinstances. These counterinstances create tension and crisis. Crisis is always implicit in research because every problem that normal science sees as a puzzle can be seen, from another viewpoint, as a counterinstance and thus as a source of crisis .

In responding to these crises, scientists generally do not renounce the paradigm that has led them into crisis. Rather, they usually devise numerous articulations and ad hoc modifications of their theory in order to eliminate any apparent conflict. Some, unable to tolerate the crisis, leave the profession. As a rule, persistent and recognised anomaly does not induce crisis . Failure to achieve the expected solution to a puzzle discredits only the scientist and not the theory To evoke a crisis, an anomaly must usually be more than just an anomaly. Scientists who paused and examined every anomaly would not get much accomplished. An anomaly must come to be seen as more than just another puzzle of normal science.

All crises begin with the blurring of a paradigm and the consequent loosening of the rules for normal research. As this process develops, the anomaly comes to be more generally recognised as such, more attention is devoted to it by more of the field's eminent authorities. The field begins to look quite different: scientists express explicit discontent, competing articulations of the paradigm proliferate and scholars view a resolution as the subject matter of their discipline. To this end, they first isolate the anomaly more precisely and give it structure. They push the rules of normal science harder than ever to see, in the area of difficulty, just where and how far they can be made to work.

All crises close in one of three ways. (i) Normal science proves able to handle the crisis-provoking problem and all returns to "normal." (ii) The problem resists and is labelled, but it is perceived as resulting from the field's failure to possess the necessary tools with which to solve it, and so scientists set it aside for a future generation with more developed tools. (iii) A new candidate for paradigm emerges, and a battle over its acceptance ensues. Once it has achieved the status of paradigm, a paradigm is declared invalid only if an alternate candidate is available to take its place . Because there is no such thing as research in the absence of a paradigm, to reject one paradigm without simultaneously substituting another is to reject science itself. To declare a paradigm invalid will require more than the falsification of the paradigm by direct comparison with nature. The judgement leading to this decision involves the comparison of the existing paradigm with nature and with the alternate candidate. Transition from a paradigm in crisis to a new one from which a new tradition of normal science can emerge is not a cumulative process. It is a reconstruction of the field from new fundamentals. This reconstruction changes some of the field's foundational theoretical generalisations. It changes methods and applications. It alters the rules.

How do new paradigms finally emerge? Some emerge all at once, sometimes in the middle of the night, in the mind of a man deeply immersed in crisis. Those who achieve fundamental inventions of a new paradigm have generally been either very young or very new to the field whose paradigm they changed. Much of this process is inscrutable and may be permanently so.

IX - The Nature and Necessity of Scientific Revolutions.

Why should a paradigm change be called a revolution? What are the functions of scientific revolutions in the development of science?

A scientific revolution is a non-cumulative developmental episode in which an older paradigm is replaced in whole or in part by an incompatible new one . A scientific revolution that results in paradigm change is analogous to a political revolution. Political revolutions begin with a growing sense by members of the community that existing institutions have ceased adequately to meet the problems posed by an environment that they have in part created. The dissatisfaction with existing institutions is generally restricted to a segment of the political community. Political revolutions aim to change political institutions in ways that those institutions themselves prohibit. As crisis deepens, individuals commit themselves to some concrete proposal for the reconstruction of society in a new institutional framework. Competing camps and parties form. One camp seeks to defend the old institutional constellation. One (or more) camps seek to institute a new political order. As polarisation occurs, political recourse fails. Parties to a revolutionary conflict finally resort to the techniques of mass persuasion.

Like the choice between competing political institutions, that between competing paradigms proves to be a choice between fundamentally incompatible modes of community life. Paradigmatic differences cannot be reconciled. When paradigms enter into a debate about fundamental questions and paradigm choice, each group uses its own paradigm to argue in that paradigm's defence The result is a circularity and inability to share a universe of discourse. A successful new paradigm permits predictions that are different from those derived from its predecessor . That difference could not occur if the two were logically compatible. In the process of being assimilated, the second must displace the first.

Consequently, the assimilation of either a new sort of phenomenon or a new scientific theory must demand the rejection of an older paradigm . If this were not so, scientific development would be genuinely cumulative. Normal research is cumulative, but not scientific revolution. New paradigms arise with destructive changes in beliefs about nature.

Consequently, "the normal-scientific tradition that emerges from a scientific revolution is not only incompatible but often actually incommensurable with that which has gone before". In the circular argument that results from this conversation, each paradigm will satisfy more or less the criteria that it dictates for itself, and fall short of a few of those dictated by its opponent. Since no two paradigms leave all the same problems unsolved, paradigm debates always involve the question: Which problems is it more significant to have solved? In the final analysis, this involves a question of values that lie outside of normal science altogether. It is this recourse to external criteria that most obviously makes paradigm debates revolutionary..

X - Revolutions as Changes of World View.

During scientific revolutions, scientists see new and different things when looking with familiar instruments in places they have looked before. Familiar objects are seen in a different light and joined by unfamiliar ones as well. Scientists see new things when looking at old objects. In a sense, after a revolution, scientists are responding to a different world.

Why does a shift in view occur? Genius? Flashes of intuition? Sure. Because different scientists interpret their observations differently? No. Observations are themselves nearly always different. Observations are conducted within a paradigmatic framework, so the interpretative enterprise can only articulate a paradigm, not correct it. Because of factors embedded in the nature of human perception and retinal impression? No doubt, but our knowledge is simply not yet advanced enough on this matter. Changes in definitional conventions? No. Because the existing paradigm fails to fit? Always. Because of a change in the relation between the scientist's manipulations and the paradigm or between the manipulations and their concrete results? You bet. It is hard to make nature fit a paradigm.

XI - The Invisibility of Revolutions.

Because paradigm shifts are generally viewed not as revolutions but as additions to scientific knowledge, and because the history of the field is represented in the new textbooks that accompany a new paradigm, a scientific revolution seems invisible.

The image of creative scientific activity is largely created by a field's textbooks. Textbooks are the pedagogic vehicles for the perpetuation of normal science. These texts become the authoritative source of the history of science. Both the layman's and the practitioner's knowledge of science is based on textbooks. A field's texts must be rewritten in the aftermath of a scientific revolution. Once rewritten, they inevitably disguise not only the role but the existence and significance of the revolutions that produced them. The resulting textbooks truncate the scientist's sense of his discipline's history and supply a substitute for what they eliminate. More often than not, they contain very little history at all. In the rewrite, earlier scientists are represented as having worked on the same set of fixed problems and in accordance with the same set of fixed canons that the most recent revolution and method has made seem scientific. Why dignify what science's best and most persistent efforts have made it possible to discard?

The historical reconstruction of previous paradigms and theorists in scientific textbooks make the history of science look linear or cumulative, a tendency that even affects scientists looking back at their own research . These misconstructions render revolutions invisible. They also work to deny revolutions as a function. Science textbooks present the inaccurate view that science has reached its present state by a series of individual discoveries and inventions that, when gathered together, constitute the modern body of technical knowledge - the addition of bricks to a building. This piecemeal-discovered facts approach of a textbook presentation illustrates the pattern of historical mistakes that misleads both students and laymen about the nature of the scientific enterprise. More than any other single aspect of science, the textbook has determined our image of the nature of science and of the role of discovery and invention in its advance.

XII - The Resolution of Revolutions.

How do the proponents of a competing paradigm convert the entire profession or the relevant subgroup to their way of seeing science and the world? What causes a group to abandon one tradition of normal research in favour of another?

Scientific revolutions come about when one paradigm displaces another after a period of paradigm-testing that occurs only after persistent failure to solve a noteworthy puzzle has given rise to crisis. This process is analogous to natural selection: one theory becomes the most viable among the actual alternatives in a particular historical situation.

What is the process by which a new candidate for paradigm replaces its predecessor? At the start, a new candidate for paradigm may have few supporters (and the motives of the supporters may be suspect). If the supporters are competent, they will improve the paradigm, explore its possibilities, and show what it would be like to belong to the community guided by it. For the paradigm destined to win, the number and strength of the persuasive arguments in its favour will increase. As more and more scientists are converted, exploration increases. The number of experiments, instruments, articles, and books based on the paradigm will multiply. More scientists, convinced of the new view's fruitfulness, will adopt the new mode of practising normal science, until only a few elderly hold-outs remain. And we cannot say that they are (or were) wrong. Perhaps the scientist who continues to resist after the whole profession has been converted has ipso facto ceased to be a scientist.

XIII - Progress Through Revolutions.

In the face of the arguments previously made, why does science progress, how does it progress, and what is the nature of its progress?

To a very great extent, the term science is reserved for fields that do progress in obvious ways. But does a field make progress because it is a science, or is it a science because it makes progress? Normal science progresses because the enterprise shares certain salient characteristics, Members of a mature scientific community work from a single paradigm or from a closely related set. Very rarely do different scientific communities investigate the same problems. The result of successful creative work is progress.

Even if we argue that a field does not make progress, that does not mean that an individual school or discipline within that field does not. The man who argues that philosophy has made no progress emphasises that there are still Aristotelians, not that Aristotelianism has failed to progress. It is only during periods of normal science that progress seems both obvious and assured. In part, this progress is in the eye of the beholder. The absence of competing paradigms that question each other's aims and standards makes the progress of a normal-scientific community far easier to see. The acceptance of a paradigm frees the community from the need to constantly re-examine its first principles and foundational assumptions. Members of the community can concentrate on the subtlest and most esoteric of the phenomena that concern it. Because scientists work only for an audience of colleagues, an audience that shares values and beliefs, a single set of standards can be taken for granted. Unlike in other disciplines, the scientist need not select problems because they urgently need solution and without regard for the tools available to solve them. The social scientists tend to defend their choice of a research problem chiefly in terms of the social importance of achieving a solution. Which group would one then expect to solve problems at a more rapid rate? .

We may have to relinquish the notion, explicit or implicit, that changes of paradigm carry scientists and those who learn from them closer and closer to the truth . The developmental process described by Kuhn is a process of evolution from primitive beginnings. It is a process whose successive stages are characterised by an increasingly detailed and refined understanding of nature. This is not a process of evolution toward anything. Important questions arise. Must there be a goal set by nature in advance? Does it really help to imagine that there is some one full, objective, true account of nature? Is the proper measure of scientific achievement the extent to which it brings us closer to an ultimate goal? The analogy that relates the evolution of organisms to the evolution of scientific ideas "is nearly perfect" . The resolution of revolutions is the selection by conflict within the scientific community of the fittest way to practice future science. The net result of a sequence of such revolutionary selections, separated by period of normal research, is the wonderfully adapted set of instruments we call modern scientific knowledge. Successive stages in that developmental process are marked by an increase in articulation and specialisation. The process occurs without benefit of a set goal and without benefit of any permanent fixed scientific truth. What must the world be like in order than man may know it?

This synopsis is an edited version created by the Philosopher's Web Magazine of an outline prepared by Professor Frank Pajares, Emory University.
