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CHAPTER 2

Definition of Science

This section is to give you more information about science so you can know more about doing and understanding those things which make you ethical and prosperous. In the previous section we saw that science is the word for the human activity which produces being ethical and prosperous. This section is a more complete elaboration of the process of science. This section is provided because the more you know of the tool "science," the better you can use it to accomplish your ends. This systematic elaboration of the process can be accomplished by way of elaborating the definition of science.

Science is very much more complex than pat definitions which you can memorize and then put the issue away. The scientific method is what has evolved to help people tell the truth and to understand the world. The following definitions are attempts at applying words to what is done so that you can gain the knowledge through vicarious experience rather than actual experience (the hard way).

I. Products of Science

A. Truth

Facts which are known to be true

- Empirical
- Reliable
- Multiple Converging Evidence
- Consensually Validated
- Operationally/functionally described
  - Explicit
  - Ontologically Valid
  - Referential Correspondence
  - Testable
  - Minimal Error
  - Systematic
  - Comprehendible

B. Understanding

Knowing the relationship of facts to each other so that you can:

- Describe
- Predict
- Control
- Synthesize
- Explain
  - Truthful
  - Explicit
  - Testable
  - Minimal Error
  - Comprehendible
  - Systematic or Principled

II. Goals of Science

The process of science typically has one of three goals.

A. Research to Understand (pure research)

Pure research is concerned with developing valid, complete, and coherent descriptions and explanations. It is interested in organizing data into the most general and parsimonious laws or qualified statements of uniformity. The emphasis is on comprehension or understanding. It is motivated by curiosity and inquisitiveness about natural phenomena. It is interested in data and relationships for their own sake. Most often the details of the research are considered arbitrary; the fundamental process is the focus. Pigeons pecking for food is the arbitrary, irrelevant aspect; behavior under the control of reinforcers is the important point. Doing this type of research is like learning a language; once it is known, all things can be done. Benjamin Franklin was engaged in pure research when he tried to compare lightening with static electricity generated by feet rubbing on a rug. He did not do it to find a better way to illuminate Philadelphia at night nor how to transmit TV pictures. He just wanted to "know." It is interesting to note that 200 years later, few Americans would survive a single year if electricity suddenly disappeared altogether. The practical impact of his indulgence of his curiosity is almost unimaginable. His discoveries are all the more impressive considering that his only reason was to add to the knowledge base. He did not do it for the money. He would not have had an answer to a critic who asked "just how will this help the human condition and if you don't know, then you should do something more practical." Studying the nature of cell growth would be pure research. Trying to describe and understand the determinants of matching would be pure research.

B. Research to Solve a Particular Problem (applied research)

Applied research is concerned with the discovery of solutions to practical problems and places its emphasis upon those factual data which have more immediate utility or application. The emphasis is on control. Applied research is like learning phrases needed to accomplish a variety of specific things in a foreign language without really understanding the whole language. The search for a cure for cancer is an example of applied research; discovering a solution for manic depression is an example of applied research.

C. Dispensing Solutions (practitioner / technologist)

Practitioners are concerned with the direct application of principles and theories from one or more fields of science for the purpose of dispensing solutions to individual human problems rather than being concerned with the discovery and organization of knowledge. Strictly speaking, a practitioner is not a scientist, but that is not to say they are necessarily unscientific. Practitioning is like memorizing sounds of a song in a foreign language without necessarily knowing the language. It accomplishes an immediate specific end. While a practitioner may uncover a phenomenon of great importance to the understanding of nature, that is not their primary focus. A practitioner or technologist administers chemotherapy or psychotherapy. A physician or a psychotherapist is a practitioner.

III. Lexical Definitions of Science

These dictionary-type definitions are not laid down by some authority such that if you stay within the letter of a definition then you are correct and are called a scientist. They attempt to communicate with “25 words or less” what science is all about.

Science uses unconfounded empirical tests to develop, discover, and explain systematic frameworks within which relationships can be explored.

Science is a knowledge generating activity which is based on systematically organized bodies of accumulated knowledge obtained through objective observations.

Science is not so much concerned with accumulating highly precise and specific data (although it is necessary) but rather science seeks to discover uniformities and to formulate statements of uniformities and consistencies of relationship between natural phenomena.

Science is to understand, explain, and predict by specifying the systematic relationships among empirical variables. It must be consensually valid and general. It must not be on authority, sloppy, or simply to "better" mankind.

IV. Activities of Science

Science can also be defined in terms of the activities of its practitioners. These activities and their explanatory system differ somewhat depending on the stage of maturity of the research area.

A. Noticing a Phenomenon

1. Type of Activity

Unsystematic specification of events. The beginnings of a conceptualization of the problem or issue. Separation of occurrence from nonoccurrence (nominal scaling). Defining and specification of elements. Formulation of productive questions. Design of subsequent investigation.

2. Type of Explanation

No explanation at all or simply general, qualitative, correlative explanations with only analogic support.

B. Casual Manipulation of Empirical Variables

1. Type of Activity

Manipulations applicable to other investigations, "art" what happens if I do xxxxx. Isolated measurement. Measurement of variables. Description of the static and dynamic properties of the phenomenon. Ordinal - ratio scales. Accumulation of data.

2. Type of Explanation

General qualitative correlative explanations with slightly more than analogic support.

C. Specification of Functional Relationships

1. Type of Activity

Informal. Difficult to articulate programmatic rationale but easy to get consensual validation of acceptable procedures and data. Meaningful classification and summarization. Parameter estimation. Extension to new areas. Delineation of rules. Development of theory. Discussion of the implications. Specification of a thing's relationship with covariates. Specification of a thing's controlling factors.

2. Type of Explanation

Explanation by specification of network of relationships. Documentation of how elements are interrelated and the functional relations among them. The emergence of quantitative prediction.

D. Specification of Coherent Explanatory System

1. Type of Activity

Specify a thing's controlling factors, and the integration of that relationship within a larger framework. Hypothesis testing. Formal clearly articulated paradigmatic rational. Procedures obvious. Formation of predictions and the development of generalizations. Hypotheses formed and tested. When successful, the theory is upheld; when if fails, the theory is modified.

2. Type of Explanation

Explanations by theory. A theoretical model is advanced which specifies how elements are interrelated.

E. Application of a General and Integrated Mechanism of Prediction (Law)

1. Type of Activity

Apply rules to solve known problem or show how obtained data are examples of law (normal science). Development of applications. Synthesis of new behaviors. Extend solution to new problem. Realize new question.

2. Type of Explanation

The law is used to explain other behaviors. The law "has paid its dues." Any counter examples are seen as the result of the operation of some other factors. A great many observations support it and virtually no findings are inconsistent with the law.

V. Assumptions of Science

As an alternate way to communicate the nature of science, its basic assumptions can be specified. These are issues which are so fundamental as to be unprovable, therefore they are assumed to be true or are assumed to be effectively the case (e.g., this all may be a dream but these are the rules in the dream) If you violate them you will have trouble convincing others of the merits of your work. For example, if you explain an FR pause by saying: “the pigeon was transformed into a rock temporarily,” most reasonable people will think you are crazy.

Space is real.
Time is real.
Matter is real.
What exists, exists in some amount.
The universe can be described in an orderly manner.
All events are determined.
Humans are capable of understanding their universe.

While we must accept that these assumptions could be wrong (e.g., beginning tomorrow, time may begin running backwards, the truck racing towards the place you are standing may not really be composed of “real” matter, etc.), unnecessary, serious and lengthy argument over the common meaning of these statements is generally left to sophomores and philosophers. The day-to-day practice of psychology simply presumes they are true as a matter of practicality, and moves on.

In point of fact, none of the assumptions need be accepted as fundamentally true; all can be seen as nothing more than a practical convention, the reality of which is irrelevant unless a discrepancy is proven to occur. Nothing is lost from the common level meanings if reality is considered as actually only a construct, but one that is so accurate that serious disagreements don’t result in any practical change in the common level meaning.

VI. Proscriptions of Science

A sixth way to view science is in terms of its operating rules. These are statements of what has been shown to work in the past. Science has consistently demanded that its knowledge base be true: (in other words)

- empirical
- reliable
- multiple converging evidence
- consensually validated
- operationally/functionally defined
  - explicit
  - ontologically valid
  - referential correspondence
  - testable
  - minimal error
  - systematic
  - comprehendible

Science has consistently demanded that its practitioners understand its knowledge base: (in other words)

- describe
- predict
- control
- synthesize
- explain
  - truthful
  - explicit
  - testable
  - minimal error
  - comprehendible
  - systematic or principled

Science has been impartial and impersonal.

Science has not been involved with morality.

It is a fact that cyanide kills people regardless of how we feel about the morality of giving cyanide to people and regardless of the circumstances under which this knowledge was discovered. Facts are facts. The issue is not that scientists have the right or obligation to be immoral. They do not. Morality comes no easier to individual scientists than it does to individual religious leaders. The issue is that like it or not, facts are facts.

Science has maintained vigilance over its method.

Science has suspended judgment when in ignorance.

Science has had tentative belief systems or theories.

Scientific belief systems are simultaneously absolute and tentative. The dynamics of this seeming oxymoron is covered in the section on paradigms.

VII. Misconceptions About Science

There are many misconceptions about the nature of science. Science can be defined in terms of what it is not.

1. Accumulation of facts is not the primary goal of science. The discovery of the unifying principle is the essence of science. This misconception is one of the major stumbling blocks for beginners. Any particular functional relationship between some specific stimulus and a specific behavior is of little consequence. Of very great importance is a particular functional relationship as an instantiation of a more fundamental, more general relationship between very large classes of events. It is the general rules which are of value.
2. No science is exact in that all sciences are empirical and empirical reality has an infinite degree of precision.
3. Science attempts to understand a phenomenon by assessing the impact of one variable or a very few variables at a time. But this is not unique, it is not possible to consider all possibilities at once in anything, even in poetry.
4. Science is not concerned primarily with providing for man's needs, but rather with understanding the universe.
5. Science does not have the obligation to disprove every assertion offered by a flake. The burden of proof is on the unusual assertion not the well-documented body of knowledge. Otherwise, progress on understanding real issues would be sidetracked.
6. Theory and reality are not different. To say it works in theory but not in the “real” world is to misunderstand the process of science. If a theory does not predict in new situations, a key element is obviously missing. One that either the speaker forgot or one that no one suspected before. For example, if a leaf is dropped on a windy day the proper phrase is not “gravity works in theory but not in the real world,” but rather, “gravity works on both leaves and on air; additionally air current ....” Using the random dot stereogram metaphor, if someone learned to memorize names to go with pictures rather than the real image, then they make serious errors of prediction because they think it is the surface picture that's important.
7. The object of scientific research is not to discover the unique inexplicable finding but rather to see the commonalities in very diverse phenomena and to show how things are examples of the same laws.

VIII. Motivations Driving Science

Yet another perspective would emphasize the motivations underlying a scientist's behavior.

A scientist is curious. They ask the question "why." They want to know why things work the way they do and nothing less than the truth will do for an answer. Their goal is to minimize the mysteries in the universe by obtaining knowledge through direct observation of particular aspects of the universe.

Scientists work very hard at unraveling the universe by using known and accepted principles. For example beginning with the theory that matter does not disappear, a scientist may try to unravel a performance of a magician. Demonstrating exactly how the trick worked with known and accepted principles of physics would prove the scientist an expert puzzle solver. Alternatively starting with the assumption that people are dying as the result of some disease organism, a scientist can set out to solve the puzzle of just how they are dying and what will stop it. "The challenge is to succeed in solving a puzzle that no one before has solved nor solved so well." As with all challenges "the puzzle must be difficult enough to prove one an expert puzzle solver, but still be solvable."

In a way therefore, science can be seen as a game or as puzzle solving in that it has rules and it is intrinsically fun. That is not to say however that it is messing around nor that it is not laborious. "For the scientist who plays the game for understanding rather than practical advantages, it is a game whose chief delights are the addition of one neatly contrived stroke that helps give form to a picture. A game affording a glimpse of what no one has conceived before. A game from which may come the ecstasy of bringing order out of chaos."

In this regard the goals of science can be recalled. Basic research is the attempt to solve the puzzle of nature.

IX. Paradigms: The Mechanism Underlying the Success of Science

The process of science from a historical perspective provides still another insight into what science is. The mechanism underlying how science maintains confidence in its predictive models (i.e., accepts what it knows as fact) but yet changes when new knowledge is discovered is complex.

There is no rule that you can mindlessly follow. "Reality," "truth," and "understanding" are actually only best approximations. Facts are facts and they are absolute and command absolute authority .... until they "change"! What you see with your own eyes is "real," what a group sees with its own eyes is "real," however it is possible that new information will make it clear that what you thought you had been seeing (that is the interpretation you placed on it) was actually a mirage, much like what a child "sees" when watching a magician. The coin is in fact no longer visible (what you actually saw) but it did not vanish in the sense of being converted to air (the interpretation children usually place on it).

The problem is that our knowledge base must advance as we learn more. It must change and the old must be seen as wrong. But at the same time, we must consider what we know as fact. We cannot assume that nothing is real and that all things are simply a matter of opinion and will soon change. We cannot believe in nothing. The reality of divorce is no reason not to love your spouse. The reality that elections change government leaders and that laws change is no reason to refuse to accept any law or any government.

The dynamic mechanism underlying science involves the codification of observations around some presumed "process in nature" or "natural law" and the belief in that causal system until multiple converging evidence overwhelmingly leads to a correction, after which a different underlying process is accepted as causing the sense data, such that the new perspective is even more coherent than before.

Such a revolution occurred when astronomy shifted from the earth-centered solar system of Ptolemy to the sun-centered system advocated by Copernicus.

A metaphor for a paradigm would picture people probing the bottom of a muddy lake with poles, trying to identify what fell into the lake. Some observations result in high spots, some indicate a muddy bottom. After many observations someone comes up with an idea about the nature of what it must be (e.g., a steam shovel). This perspective which integrates observations is the "paradigm." Probing the bottom to see if it is true is "hypothesis testing." Showing how all the observations can be explained by the proposed object is what engages most researchers most of the time.

A. "The Structure of Scientific Revolutions"

Thomas Kuhn described the mechanism underlying the historical/social development of science in "The Structure of Scientific Revolutions." In an attempt to help you get the points of a relatively complex picture when you read the book; a chapter by chapter summary follows.

1. A Role for History

The way of viewing the world and how it works based on a theory with its tools and important questions is called a Paradigm. Adults have a paradigm that matter does not cease to exist. They "see" a magician from that paradigm. Children have a paradigm that anything is possible. They "see" a different thing. In a sense, it is the difference between children and adults, an inadequate paradigm versus an adequate one.

As we will see, the history of knowledge is rather like what happens when you look at a Necker cube. At first we organize our sense data in terms of one organizing principle, then later we organize the same sense data in terms of some other organizing principle. At first our view is that the cube is slanted one way, then later our view is that it is slanted another way. This is not to say that while we are viewing it the first way we could suggest that its shape is completely arbitrary and it subsequently may appear as a circle. A flaw in the Necker cube analogy is that science does not flop back and forth. Science moves continually toward more and more useful views. Possibly a better analogy would be an Ames room. At first we are struck by its rectangularity. Later we appreciate its trapezoidal nature. The key point in both metaphors is that we must believe our eyes (as we can best interpret) until we have enough evidence from enough sources to be confident that we should place another interpretation on what we see.

2. The Route to Normal Science

A paradigm is a frame of reference. A paradigm is a view of the world which attracts adherents and provides problems to be solved.

A group of interacting and cross validating people working on answering a problem are interested in some questions and not others. A paradigm is the common view of a group of scientists.

The group comes to agree about certain things:

1. what data are real
2. what explanations work
3. what questions will help understand or help extend the explanation and which will not
4. after a while these people will "get it on" - they consider all the first level issues and go on to the second level. If you walk in ready to talk about the first level issues, they have already dealt with these and they will not be interested. A newcomer should listen, pickup on what is happening and then butt-in. Formally speaking a science is into recondite problems and has given up trying to communicate to the lay or trying to make the lay understand or accept what the science is doing.

Paradigms do not attempt to deal with all possible conflicting findings, each excludes some facts.

A paradigm leads to esoteric research which is a sign of maturity. If each scientist must reestablish the foundation no headway is made.

Scientists take the foundation of their field for granted. From that point they push on to more abstract and recondite problems and increasingly they report their results in articles addressed to other specialists rather than in books addressed to the general public. A conversation group at a party cannot make much headway if it is constantly explaining the beginning of the story to newcomers.

Normal science means research firmly based on past scientific achievements that some particular scientific community acknowledges for a time as supplying the foundation for further practice.

3. The Nature of Normal Science

Normal science is the practice of gaining knowledge by using some paradigm. It therefore has a perspective, common rules, facts, and problems. Its task is to solidify, reify, and articulate the paradigm; quantify its predictions, extend it to new areas, and to develop the technology needed. It rejects the approbations of the lay. It does not attempt to answer all problems. It uses facts considered revealing to solve problems considered acute by the paradigm. It is to articulate accepted phenomena. Problems must be challenging but not hopeless. Frequently the paradigm and its rules are tacit, they cannot be articulated. The adequacy of a paradigm is judged by peers not lay.

Normal science is the finding of previously unpredicted phenomena and showing how that phenomena is explainable with the existing paradigm. Finding unexplainable phenomena is not science; anyone can be capable of not explaining something. Brain damage helps enormously. Normal science does not produce new phenomena; it articulates those that the paradigm supplies.

Extending the paradigm (showing how the paradigm explains previously unexplainable events) is mopping up and is where most scientists spend their lives.

A paradigm gains status because it handles problems that practitioners feel are important - not because it handles all problems.

Foci for factual scientific investigation.

1. Empirical work to articulate paradigm or theory. Determinants of physical constants / quantitative laws / determination of way to apply paradigm to new situation.
2. Facts without intrinsic interest which can be compared to predictions from the paradigm.
3. Class of facts that the paradigm has shown to be revealing of nature.

To desert the paradigm is to cease practicing the science it defines. The task is to explain current problems with rules such that the majority of past findings are consistent, somewhat like a judge trying to be consistent with precedent, or trying to minimize sum of squared differences when determining a regression line.

4. Normal Science as Puzzle Solving

The task of solving a challenging problem within a strong network of rules or commitments - conceptual, theoretical, instrumental, and methodological is a principle source of the metaphor that relates normal science to puzzle solving.

Normal research is not to produce novelty. Research questions must offer a challenge but still be solvable.

The solution must fit the paradigm to be "legal." People work very hard at achieving the theoretically expected or predicted and therefore prove themselves expert puzzle solvers. The theory predicts that the magician did it with slight of hand. The scientist tries to discover how. The master detective outwits the criminal and proves himself an expert puzzle solver.

5. The Priority of Paradigms

A paradigm modifies how we view things much as our perspective governs how we see a Necker cube or some other Gestalt pattern. Frame of reference within which nature is viewed. Perspective shading our view. A paradigm is a set of: common rules common facts common problems

It is very difficult to explicitly specify the rules which demark a paradigm. Few people can document the actual rules of grammar but most people speak correctly.

Much success depends on tacit knowledge. Knowledge that is acquired through practice and that cannot be articulated explicitly.

Paradigms can determine normal science without the formulation of explicit rules.

Often scientists do not have a very good understanding of the foundation of their paradigm and make substantial errors when their niche changes (e.g., average physicists and tricksters).

Deep argument over legitimate methods and problems serve to define schools more than produce agreement.

Deep debates occur just before revolutions.

6. Anomaly and the Emergence of Scientific Discovery

When something new happens its meaning is deeply tied to a paradigm. The isolation of some phenomena which does not fit the existing paradigm and the emergence of a new paradigm may be temporally separated.

A key event is the discovery of an anomaly for which the paradigm has not readied the investigator. What is an anomaly for someone who does not understand the paradigm or who cannot find the solution may not be an anomaly for an educated person. Von Daniken sees more anomalies than does a trained archeologist. Amateurs and scientists both look for a new paradigm when the existing body of knowledge and their puzzle solving ability no longer works. It's just that amateurs run out of reasonable explanations very quickly while a scientist's paradigm is enormously more productive.

Characteristics of a growing paradigm crisis:

1. Growing number of anomalies.
2. Gradual and simultaneous emergence of both observational and

conceptual recognition.

3. Consequent changes of paradigm categories and procedures often accompanied by resistance.

7. Crisis and the Emergence of Scientific Revolutions

Sooner or later the paradigm or model begins to strain. People have difficulty accounting for new data with the paradigm. New data from new areas as well. Generally a problem both considered important, well-documented factually and consensually valid but at the same time anomalous occurs. This leads to the formulation of primitive explanatory systems not strictly consistent with the paradigm. Eventually these explanatory systems become incompatible with the accepted paradigm. If the new paradigm:

1. works on most cases
2. provides greater explanatory power
3. salvages most of the old paradigm's knowledge
4. attracts articulate adherents

then it can supplant the old paradigm.

When the complexity of a paradigm increases faster than its explanatory power and when the whole milieu is pushing for change then there tends to be a proliferation of competing theories.

Novel theories emerge only after pronounced failures in normal problem solving activity.

Problems start about a decade before the change.

Frequently solutions are anticipated earlier during noncrisis.

Retooling however is an extravagance to be reserved for occasions which demand it.

Gain is achieved only by discarding some previously standard beliefs or procedures and simultaneously replacing those components of the previous paradigm with others.

8. The Response to Crisis

Normal science does and must continually strive to bring theory and fact into closer agreement. That activity can easily be seen as testing or as a search for confirmation or falsification. Instead its object is to solve a puzzle for whose very existence the validity of the paradigm must be assumed. Failure to achieve a solution discredits only the scientist not the theory.

Copernicus saw as counter instances what most of Ptolemy's other successors had seen as puzzles in the match between observation and theory.

Anomalies are usually not considered counter-instances but rather simply puzzles.

New paradigms come from people new to the field or young or both.

Once it has achieved the status of a paradigm a scientific theory is declared invalid only if an alternative candidate is available to take its place.

9. The Nature and Necessity of Scientific Revolutions

Scientific revolutions are inaugurated by a growing sense, again often restricted to a narrow subdivision of the scientific community that an existing paradigm has ceased to function adequately in the exploration of an aspect of nature to which the paradigm itself had previously led the way.

Unanticipated novelty can emerge only to the extent that anticipation about nature and instruments prove wrong.

The biggest clash comes where the normal paradigm is overextended beyond the facts or into areas without precedent that have not yet been conceptualized. But paradigms must be assumed to work beyond the present facts to be useful.

The paradigm must change in ways that the paradigm prohibits.

The arguments are not logically compelling but do give a view of the new paradigm.

Once the split occurs reconstruction is impossible because each paradigm appeals to itself for defense.

Three types of phenomena about which a new paradigm could develop.

1. Phenomena already well-explained by existing paradigms. This is unlikely because there is no compelling need nor reason to change.
2. Phenomena whose nature is indicated by existing paradigm but whose details can be understood only through further theory articulation. This is unlikely because it requires only normal science.
3. Recognized anomalies whose characteristic feature is their stubborn refusal to be assimilated to existing paradigms.

The change in paradigms changes what are thought to be significant problems.

Although an out of date theory can be thought of as a special case of a present paradigm it must be transformed into the new paradigm. If that is done the statements no longer have any meaning.

10. Revolutions as Changes of World View

Led by revolution scientists adopt new instruments, look in new places, more importantly they see new and different things when using familiar instruments in places they looked before.

At first there were no pendulums, only swinging stones for the scientist to see. Pendulums were brought into existence by something very like a paradigm induced gestalt switch.

What occurs during a scientific revolution is not fully reducible to a reinterpretation of individual and stable data it is like a Gestalt shift: same data, new interpretation.

Things which could not be seen by Aristotelians were the consequences of immediate experience for post Galileans.

One is tempted to say that the chemists who viewed solutions as compounds differed from their successors only over a matter of definition. In one sense that may have been the case but that sense is not the one that makes definitions mere conventional conveniences. In the 18th century mixtures were not fully distinguished from compounds by operational tests and perhaps they could have been but even if chemists had looked for such a test they would have sought criteria that made the solution a mixture.

For Dalton if the mixture did not have a fixed proportion it ipso facto was only a mixture - so any proof of a counter example to his theory was just interpreted as a mixture.

11. The Invisibility of Revolutions

It is difficult to see the revolutionary nature of science because current history or text books are written from the current paradigm and reinterpret the past as instances of the present view.

12. The Resolution of Revolutions

In hindsight the old is a subset of the new but only with a change in view. Revolutions are made invisible by textbooks because they view the past with the perspective of the new paradigm. The big difference is that the old is no longer boundless. It now has restricted range. Part of practicing a paradigm is to expand the old paradigm. It is always successful if limited to its data base.

Any new interpretation of nature whether a discovery or a theory emerges first in the mind of one or a few individuals. It is they who first learn to see science and the world differently. Their ability to make the transition is facilitated by two circumstances that are common to most other members of their profession. Invariably their attention has been intensely concentrated upon the crises provoking problems usually in addition they are researchers so young or new to the crisis ridden field that practice has committed them less deeply than most of their contemporaries to the world view and rules determined by the old paradigm.

Lifelong resistance particularly from those whose productive careers have committed them to an older tradition of normal science is not a violation of scientific standards but an index to the nature of scientific research itself. The source of resistance is the assurance that the older paradigm will ultimately solve all its problems.

If a new candidate for a paradigm had to be judged from the start by hard headed people who examined only relative problem solving ability the sciences would experience very few major revolutions.

The proponents of competing paradigms practice their trades in different worlds. What cannot even be demonstrated to one group is intuitively obvious to the other.

The research worker himself is not a tester of paradigms; his quest is for solutions to puzzles. He may, in fact, try many paths for a puzzle's solution and in each one find unacceptable results, but he is still not testing the paradigm. The research worker may be likened to a chess player, who also may try many solutions to solve the puzzle of the game before him. The chess player may meet each trial with failure, but these are trials in and of themselves, not trials of the rules of chess. Paradigms are not tested in a single comparison with nature, but when the existing paradigm consistently fails to solve a particular problem, crisis occurs. In result, the existing paradigm is placed in competition with a rival, both competing for the homage of the scientific community.

13. Progress Through Revolution

The effect of sensitivity to lay approbation is consequential. If all members of a community responded to each anomaly as a source of crisis or embraced each new theory advanced by a colleague, science would cease. Most scientific advancement is normal science. If on the other hand no one ever reacted to anomalies or to brand new theories in high risk ways, there would be few or no revolutions.

The very existence of science depends upon resting the power to choose between paradigms in the members of the special community.

The problems must be problems of detail. The solutions that satisfy a researcher may not be merely personal but must instead be accepted as solutions by many scientific peers.

The scientific community is a supremely efficient instrument for maximizing the number and precision of the problems solved through paradigm change.

A new paradigm:

1. resolves some outstanding generally recognized problem that can be met in no other way
2. the new paradigm must promise to preserve a relatively large part of the concrete problem solving ability that has accrued to science through its predecessors.

Science develops from primitive beginnings not toward some goal any more than evolution is moving toward a goal. Once the reception of a common paradigm has freed the scientific community from the need to constantly re-examine its first principles the members of that community can concentrate exclusively upon the most subtle and most esoteric of the phenomena that concern it.

The practice of normal science depends on the ability acquired from exemplars to group objects and situations into similarity sets which are primitive in the sense that the grouping is done without an answer to the question "similar with respect to what?" A central aspect of a revolution is that some of the similarity relations change.

14. Summary

Kuhn provides the solution to a number of very thorny issues:

1. Reality is, and can only be, our best model of it
   a. There is no way for anyone to know reality and then to evaluate what is sensed or what is believed against it.

2. Ultimately, a paradigm's description of reality might be wrong, but it must be assumed to be right.
   a. it is after all the best we have
   b. we cannot make progress if every time there is a discrepancy between observation and theory, we presume the theory is wrong.
   c. The traditional models are very broad systems which account for a vast array of phenomena with a minimal number of basic laws. The novel abrogates many explanations by abrogating the paradigm.
   d. A paradigm with respect to natural phenomena is much like a regression line with respect to data points. The paradigm gives an articulable and systematic account for as much of the variance found in nature as possible. Individual outliers are not normally seen as abrogating the paradigm but rather as anomalies which can be accounted for with normal science. Occasionally so many outliers are discovered that their accumulated weight changes the paradigm just as a great many outlying data points change a regression line. The important realization is that the optimum conceptual strategy is to go with the paradigm which accounts for the maximum variance. It is risky to give an outlier more importance than it deserves.

3. We cannot sit back and believe nothing until the infinite future arrives so that we know that our model will not change with additional information.

4. Our model of reality must in some ways be considered as more fundamental than our direct experience.
   a. How we must interpret our sense data is with respect to what is most likely, or most consistent with what is known. Additionally, the information we seek is governed by what we think is interesting or important which is in turn based on our paradigm.
   b. This view which suggests that the naively perceived natural world is not the final arbiter of reality does not imply that "an invisible gorilla stole your money, not me" is a legal explanation. Our paradigm does not allow the self-serving postulation of invisible thieves. The paradigm requires consensual validation and a systematic, consistent framework.
   c. It is important to keep in mind that measurements are not arbitrary and changing with the whim of the current paradigm. It is only what they mean that can change. It may have been a crane that fell into the lake rather

than a steam shovel. The high spots and their positions remain. The moving dot of light in the sky still moves first to the right then to the left then back to the right again. However, planets no longer backup. They only seem to backup because of the movements of the earth and the planets. Coins are still no longer visible after being touched by the wand, however, they do not vanish, rather they only disappear from sight.

5. Our models must be evaluated on several dimensions simultaneously.
   a. empiricism - anything that is to be considered real must result in some way in reliable sense data
   b. consistency with paradigm - it must be a result that is possible. Coins do not vanish from a magician's hand, they must be seen to move.
   c. consensual validation - it is only by consistency with a paradigmatic community that our observations have meaning.

6. Overview of Paradigms
   a. World view that has been shown to be productive in providing explanations, i.e., predictions that work.
   b. That world view is assumed to be true. Failure to explain with it simply means the person cannot apply it correctly.
   c. The paradigm is right. It is the way it is. The task of the scientist is to show that everything is an example of the paradigm or is an error.
   d. Task is to figure out how paradigm explains problems not how paradigm does not. Anyone can make something not work. The task of science is to unmask tricksters not to be fooled by new ones.
   e. One question's answer leads to another question - esoteric research is the result.
   f. Some research questions are thought to be more revealing than others - rather like sheer lines in a diamond.
   g. Control of paradigm is in hands of its practitioners.
   h. Science is social or subjective in nature but very much closer to reality than anything else.
   i. Paradox: Progress only through showing how the establishment is right (normal science), while at the same time long-term progress requires changing the paradigm (revolutionary science).

B. Case History of a Scientific Revolution

History of controlling malaria - the evolution of better paradigms.

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