The Structure of Scientific Revolutions

INTRODUCTION

BRIEF BIOGRAPHY OF THOMAS S. KUHN

Thomas Kuhn, the son of engineer Samuel L. Kuhn, was born in Cincinnati and raised in between New York City and Croton-on-Hudson. Though he is thought of as a historian and philosopher, he started off his career as a physicist—in fact, he had almost finished a physics doctorate at Harvard before an encounter with Aristotle's work (so dramatically different from the contemporary theories he was familiar with) piqued his interest in the history of science. After transitioning to work in the humanities, Kuhn began teaching at various universities (including Princeton and M.I.T.) and developing the argument that would later become his masterwork, *The Structure of Scientific Revolutions*. After its publication in 1962, Kuhn's radically new conceptualization of scientific progress—famous for having made the word "paradigm" a part of daily speech—sparked debates across many academic fields. Kuhn spent the next decades of his life revising his initial theory (as he does in the 1969 postscript to the original book), teaching, and raising his three children. By the time he died in 1996, he was widely considered to be the 20th century's most important philosopher of science.

HISTORICAL CONTEXT

Since *The Structure of Scientific Revolutions* is fundamentally a history book, Kuhn touches on a wide variety of historical events. Two such events, however, stand out for their influence on Kuhn's own thinking. Before he wrote *The Structure of Scientific Revolutions*, Kuhn had written a book about the Copernican Revolution, the moment in 1543 in which Nicolaus Copernicus overturned the long-held belief that Earth, and not the sun, was at the center of the universe. Even more crucially, Kuhn's fascination with the history of science was sparked by his understanding of the huge gulf between classical ideas of physics (like Aristotle's) and Isaac Newton's 1728 concepts of motion. Finally, the rising prominence of Gestalt psychology—which focused on the inconsistency of perception—was a major influence on Kuhn's own thinking.

RELATED LITERARY WORKS

In many ways, *The Structure of Scientific Revolutions* pushes back against the predominant scientific literature of Kuhn's time: namely, high school and college textbooks that presented scientific history as straightforward and neat. However, though Kuhn's theory was radical, he was not the first person to question this simplistic narrative. Gaston Bachelard, a French philosopher, had held for decades that scientific was more discontinuous and less objective than it seemed. Like Kuhn, Bachelard was interested in epistemology (the study of what knowledge is and how it develops), which he wrote about in his book *Formation of the Scientific Mind* (1938). In addition, Michel Foucault, Kuhn's contemporary and author of such famous books as *The Birth of the Clinic* (1963) and *The Order of Things* (1966), was similarly trying to understand science as the product of social forces in addition to mere observation.

KEY FACTS

- **Full Title:** The Structure of Scientific Revolutions
- **When Written:** 1950s–1960s
- **Where Written:** Cambridge, Massachusetts
- **When Published:** 1962
- **Literary Period:** Mid-century
- **Genre:** Nonfiction, Science, History
- **Setting:** While the book is a global history of science, most of the discoveries Kuhn focuses on were made in Western Europe.
- **Climax:** Kuhn, arguing that scientific progress is neither linear nor cumulative, claims that scientists are not getting any closer to a single, objective truth—because no such thing exists.
- **Point of View:** First Person

EXTRA CREDIT

Cited and Celebrated. Though *The Structure of Scientific Revolutions* had obvious implications for scientists themselves, it was also influential across disciplines: sociologists, philosophers and even economists argued against the book or used it in their own work. It follows, then, that it is one of the most-cited academic works of all time, an impressive achievement for a book published only 50 years ago.

Paradigm Shifts Galore. The term "paradigm shift," which Kuhn uses to describe the process by which one set of scientific perceptions and questions replaces another, is now commonplace in popular culture. But to ensure that the term remains associated with the man who made it famous, the American Chemical Society created a prize called the Thomas Kuhn Paradigm Shift Award, given out to only the most original thinkers in chemistry.

PLOT SUMMARY

In the introduction, historian and philosopher of science Thomas Kuhn lays out a radically new conception of scientific discovery. Most people, raised on simplistic science textbooks, believe that scientists make straightforward, linear progress toward objective truth. But Kuhn believes that the history of science is more circular than linear in nature, and that by teaching people to look at the history of science in this way, he can help reshape the popular view of what science is and what it can accomplish. Specifically, he argues that the study of the natural world develops through a perpetual cycle of scientific revolutions, in which one set of questions and "arbitrary" perceptions are replaced by a different—though not inherently better—set of scientific beliefs.

To dig deeper into his argument, Kuhn begins by describing what he calls the process of normal science. Normal science is what takes place once one transformative insight or discovery has created a new "paradigm," or a collection of perceptions, rules and strategies that define a certain scientific era. In normal science, scientists learn about these rules and strategies through textbooks and then work to apply them to a variety of problems.

Kuhn argues that normal science, which is what the vast majority of scientists spend their days doing, actively discourages new and original thinking. Instead, the goal of normal science is "attempt to force nature into […] the box that the paradigm supplies." In other words, normal science entails working to prove and specify a given theory, not to alter it. Normal science is useful because it allows scientists to focus on a specific set of problems and build on one another's work instead of constantly arguing with one another.

However, sometimes in the course of normal science, someone notices an anomaly that the theory fails to explain. As more and more people start to pick up on this anomaly, an intellectual crisis breaks out. Various researchers try to defend the existing theory in different ways, and the scientific community starts to splinter. Eventually, Kuhn suggests, one brilliant thinker has an almost instantaneous, intuitive revelation—and a new scientific theory, able to explain the anomaly, is born. Over time, this person's theory persuades more and more scientists, and a new paradigm takes hold.

Kuhn calls the process by which one paradigm replaces another a "scientific revolution." To illustrate this process, Kuhn provides several examples of such revolutions. For instance, Nicolaus Copernicus's 1543 realization that Earth rotates around the sun uprooted centuries of belief in a geocentric universe. Another example is Antoine Lavoisier, whose work in chemistry suggested that combustion was not an intrinsic property of certain chemicals but rather the result of different compounds reacting with one another.

Through his examples and analysis, Kuhn draws several conclusions about the nature of scientific revolutions. First, he asserts that normal science—though it discourages new discovery—is ultimately what makes scientific revolutions possible. In order to notice an anomaly, scientists need to know what specific things to expect, and that is exactly what normal science teaches them to do.

Second, Kuhn observes that each new paradigm tries to destroy and replace the old one rather than build on it. This is why Kuhn views scientific progress as circular rather than linear. For example, ancient Greek philosopher Aristotle believed that objects had innate natures that caused them to move in certain ways. René Descartes questioned Aristotle's theory, believing that all motion was the result of various substances bumping into one another. Most people then dismissed Aristotle's conception—until Isaac Newton theorized gravity as an innate property, putting his followers more in line with Aristotle than with Descartes. Rather than moving in a straight line, therefore, science had moved in something like a circle.

Third, Kuhn suggests that no one scientific theory or paradigm is inherently more accurate or better than another. Rather, because each theory is the product of the "arbitrary" perceptions and questions that define its time, a paradigm shift is fundamentally a change in the way scientists see and experience the world. That is why one worldview or paradigm is almost impossible to square with another (what Kuhn terms "incommensurable"). Moreover, Kuhn emphasizes that scientists are human, and that new paradigms emerge not because they have more inherent worth, but because they are more persuasive.

To conclude, Kuhn argues that because science is circular, subjective, and based on perception, it will never reach one single, objective, truth. In fact, Kuhn suggests that no such objective truth exists.

In a brief postscript to his original text, written seven years later, Kuhn responds to critics and clarifies some of his earlier points. Specifically, he emphasizes that while his theory does have some broad applications, science is a unique field because there is more professional training and less room for disagreement or creativity than in other disciplines. Finally, Kuhn calls for more study of various kinds of intellectual communities, as these are the groups that produce most collective knowledge.

CHARACTERS

Thomas Kuhn – Kuhn, the book's author and narrator, was a historian and philosopher of science fascinated by epistemology (or, the study of knowledge). His overarching argument in *The Structure of Scientific Revolutions* is that science develops and changes in a cyclical way (rather than a linear way) over time. Since Kuhn was fascinated by how people's unique personalities and perceptions shape knowledge, he acknowledged that his argument, while built mostly on historical evidence, was also a product of his own subjective intuitions. There are then several moments throughout the book where Kuhn's own self-reflective character comes through. For instance, as he tries to articulate the lived experience of a paradigm, he admits that he is "unable to explain further" what he means or how he has come to his conclusions. And even more tellingly, he devotes the entire Postscript to revising and clarifying his own conclusions. In this sense, just as Kuhn understood science to be in some way "arbitrary," he was equally conscious of this arbitrariness in his own work.

Aristotle – Aristotle was an ancient Greek philosopher who lived and worked in the 4th century B.C.E. His writing impacted innumerable fields of study, from ethics to zoology, but Kuhn is most interested in Aristotle's work on motion. Aristotle believed that objects were made up of four elements: air, fire, earth and water. Objects' motion, he believed, was the determined by the innate properties of the elements inside of them (so, for example, an object made of air would fall slower than an object made of fire). His theories of motion, known as Aristotelian physics, were later thrown into question by Galileo.

Nicolaus Copernicus – After centuries of belief in the geocentric universe (in which the sun rotated around Earth), Polish astronomer Copernicus suggested that the reverse was true. In his famous 1543 treatise *De revolutionibus orbium coelestium* (*On the Revolutions of the Celestial Spheres*), Copernicus presented a heliocentric model of the universe (in which the Earth rotated around the sun). This idea went largely unnoticed when Copernicus first announced it, but it became popular—and extremely controversial—after Galileo used new telescope technology to find evidence for the Copernican model.

Galileo Galilei – Galileo was a 16th-century Italian scientist who made important contributions to both astronomy and physics. In astronomy, he helped prove and popularize Copernicus's heliocentric model. In physics, Galileo pioneered new theories about the pendulum motion and rates of acceleration. His ideas overturned much of Aristotelian physics, which focused less on the similarities between objects and more on their innate (or elemental) differences.

René Descartes – Most famous for his declaration "*Cogito, ergo sum*" ("I think, therefore I am"), Descartes was an important 17th-century French philosopher. In addition to linking the study of algebra to the study of geometry, Descartes pioneered what Kuhn calls the "mechanico-corpuscular" view of the universe. According to this view, all things in the universe were made of tiny bodies (corpuscles), and all motion was created by these corpuscles bumping into one another. Mechanico-corpuscular physics then cast doubt on Aristotle's belief that objects had innate properties.

Isaac Newton – Though he is best known for his contributions to physics, 17th-century British scientist Isaac Newton also dabbled in astronomy, theology, and other fields of study. Kuhn is largely interested in Newton's study of gravity, which moved physics away from the Cartesian model. Kuhn also discusses Newton's desire to link math and motion, which Newton encoded in his treatise *Mathematical Principles of Natural Philosophy* (also called the *Principia*).

Robert Boyle – Boyle was a chemist who lived and worked in England and Ireland during the late 17th century. He was a believer in Descartes's model of the world, and he used this paradigm to arrive at what is now known as Boyle's Law: the volume of gas, he discovered, decreases as the pressure of gas increases (and vice versa).

Antoine Lavoisier – Lavoisier was an 18th-century French chemist. Toward the end of the 1700s, scientists across Europe were trying to understand combustion (how fire worked). Lavoisier, a prominent French philosopher and court administrator, had initially subscribed to the phlogiston theory, which dictated that there were special fiery substances ("phlogistons") in the air. As he conducted more and more experiments, however, Lavoisier began to believe that combustion was less about fiery substances and more about the way different chemical compounds interacted with one another. Ultimately, Lavoisier's experiments led him to discover oxygen as a unique compound and to develop a new understanding of chemical reactivity.

John Dalton – Dalton was an English scientist who lived during the 18th and 19th centuries. Though he initially started out as a meteorologist, Dalton ultimately became famous for his law of partial pressures, which viewed air pressure through a mechanical lens and thus cast doubt on much of Lavoisier's work. Kuhn argues that Dalton was able to gain a unique perspective on air pressure specifically because he was trained in meteorology rather than chemistry.

Albert Einstein – Einstein, a physicist famous for revolutionizing his field, was born in Germany but immigrated to the U.S. after Hitler came into power in 1933. His theory of relativity, which focused largely on the speed of light, helped unify space and time, thereby calling into question many of the principles of physics that had persisted since Isaac Newton's time.

TERMS

Paradigm – A paradigm is a set of perceptions, rules, and methodologies that scientists in a given field agree on. Paradigms are invented through extraordinary science, in which one person intuits a new way of understanding the world. Paradigms are then strengthened and applied through normal science, in which a group of scientists rely on the general ideas and techniques of the paradigm to solve a variety of increasingly specific problems. Because paradigms focus on one set of observations and questions at the expense of others, they are always, to some extent, arbitrary or subjective—but they tend to present themselves as completely objective and accurate (especially in scientific textbooks).

Normal Science – Once a paradigm is in place, normal science is the work of strengthening, proving and applying that paradigm. Normal science allows scientists to build on one another's work and to agree on a limited set of questions, tools, and methodologies; this is the kind of work that the vast majority of scientists do. At the same time, normal science—which is taught through textbooks, and which emphasizes puzzle-solving—discourages original thinking and new discovery.

Anomaly – An anomaly occurs when, in the course of normal science, a researcher sees something that does not make sense within a given paradigm's rules. Once enough scientists have noticed an anomaly, it creates a scientific "crisis," in which scientists begin to question the paradigm they have been operating under. Even though anomalies disrupt the course of normal science, normal science is (paradoxically) what makes anomalies possible: by teaching scientists exactly what to expect, normal science makes it easier to notice when something small stands out.

Extraordinary Science – If normal science discourages novelty, extraordinary science is the means by which a new scientific paradigm is conceived. While normal science is specific and predictable, extraordinary science poses a whole new set of potential problems and techniques (which will then be answered and applied by normal science). And if normal science is a group endeavor, extraordinary science is the work of an individual. Rather than being learned through textbooks, extraordinary science is intuited almost overnight (in a "lightning flash" of genius).

Scientific Revolution – A scientific revolution is the process by which one paradigm replaces another. This happens in gradually: first, some research carried out in the name of normal science uncovers an anomaly. As more people learn about this anomaly, debates break out, and scientists begin to question the initial paradigm's basic rules and ideas. Then, one person has a flash of genius and proposes a new paradigm that explains and absorbs the anomaly. Eventually, more and more scientists are persuaded by this new theory, and the new paradigm emerges victorious.

Paradigm Shift – The term paradigm shift refers to the process by which scientists learn to perceive the world differently. "When the transition [from one paradigm to another] is complete," **Kuhn** writes, "the profession will have changed its views of the field, its methods, and its goals." In other words, scientists begin to view the world from a fresh perspective, asking new questions and using new methods to find answers.

Incommensurability – Because each paradigm shift marks such a fundamental change in the way scientists experience the world, it can be very difficult for scientists working in one paradigm to talk to experts in another. Moreover, each paradigm draws on a different set of data and poses different problems—so, one group might deem that the evidence another group is using to prove their idea is irrelevant. **Kuhn** terms this gap between paradigms "incommensurability," and he argues that this is why each new paradigm is so controversial when it is first introduced.

Disciplinary Matrix – In **Kuhn**'s postscript to *The Structure of Scientific Revolutions*, he uses the term "disciplinary matrix" to clarify what he initially meant by "paradigm." Like paradigms, disciplinary matrices describe groups of scientists with a shared set of beliefs. But Kuhn specifies three crucial pillars of a disciplinary matrix: first, scientists must have a shared set of symbols and definitions. Second, scientists must have a shared set of metaphysical beliefs about the world. Third, scientists must have a shared set of values.

THEMES

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LINEAR PROGRESS VS. CIRCULAR HISTORY

From physics to chemistry to biology, science textbooks tend to present the history of science as a linear story of progress. Thomas Kuhn, a historian who first trained as a physicist, argues the opposite: in *The Structure of Scientific Revolutions*, he suggests that each great scientific discovery ushers in a new way of looking at the world (what Kuhn calls a paradigm), which then prompts a new set of scientific questions and techniques. Rather than building on the last paradigm, each new paradigm completely upends the last. Then, the new paradigm undergoes the same cycle of invention, problem-solving, crisis, and collapse. In viewing the history of science as cyclical rather than linear, Kuhn argues that science is more dependent on historical context than textbooks make it seem—in part because scientists themselves are invested in presenting their work as objective and correct rather than as one of many possible ways of tackling a problem.

Though textbooks present a linear history of science, Kuhn argues that each new paradigm in fact marks a complete break from the one before it. Textbooks tend to suggest that scientific progress is both linear and coherent—for example, by presenting Albert Einstein's physics as a direct descendant of Isaac Newton's. Kuhn, however, feels that Newton and Einstein are actually operating under two completely different paradigms. Though the two men used some of the same terms ("space," "time," and "mass," for instance), those words meant very different things to them, and to force Einstein's worldview onto Newton's earlier research is to distort the true meaning of his work. Kuhn therefore sees this insistence on linear history as harmful: "by disguising such changes," he argues, "the textbook tendency to make the development of science linear hides a process that lies at the heart of the most significant episodes of scientific development." Kuhn believes that new paradigms—and the new beliefs and experiences that go along with them—are the most essential part of understanding how scientific research grows and shifts. To suggest that each scientist is thinking along the same lines as his predecessors is to erase the messy, more human reality of how science develops in favor of a deceptively neat narrative. Kuhn further argues that, like the textbooks they learn from, scientists also tell a linear—but inaccurate—version of their field's history. As Kuhn writes, "looking at the moon, the convert to Copernicanism does not say 'I used to see a planet, but now I see a satellite.' That locution would imply a sense in which the Ptolemaic system once had been correct. Instead, a convert to the new astronomy would say 'I once took the moon to be […] a planet, but I was mistaken.'" Rather than acknowledging that each paradigm has particular values and viewpoints, scientists erase past perceptions by labeling them errors or mistakes. Kuhn's project is to show how each view (both pre- and post-Copernican, in this example) is different but equally valid.

Kuhn then demonstrates that each individual paradigm goes through the same life cycle—and that the history of science itself is often more circular than linear. Kuhn advocates for seeing "scientific development as a succession of tradition-bound periods punctuated by non-cumulative breaks." Time still moves forward, so one period must succeed the others. But Kuhn emphasizes that science is "non-cumulative"; each new crisis breaks-up ("punctuates") a field's work, causing it to start over anew instead of to continue on. On a larger scale, science often seems to loop backwards rather than move forward. To exemplify this idea, Kuhn traces the idea of motion as innate from Aristotle through Descartes through Newton. Aristotle's belief that objects had built-in properties of motion was largely discounted by Descartes' "mechanico-corpuscular" view, which dictated that all motion was created by various (uniform) particles bumping into one another. But a few decades later, Newton conceived of gravity, an innate type of motion that was quickly and broadly accepted. This cycle in history stands as a testament to Kuhn's non-linear, looping history of science. Even the structure of Kuhn's book reflects this cyclical view of time: rather than moving chronologically through science, Kuhn moves through the stages of each scientific revolution. As he moves from chapters like "Normal Science as Puzzle-Solving" to "Anomaly and the Emergence of Scientific Discoveries," Kuhn maps a single pattern that repeats itself again and again over time. He even provides cross-historical examples for each chapter, tracing Galileo and Newton's paradigms from their beginnings to their crises to their collapses. By focusing on this repetitive structure, Kuhn trains his readers to think of scientific history as circular repetition, not as linear advancement.

Though scientists try to validate their own paradigm by erasing the ones that have come before, Kuhn insists that a true historian of science must always acknowledge the radical differences between various paradigms of scientific thought. He argues that scientists are particularly likely to rewrite history in their favor, in part because science—which positions itself as objective and grounded fully in the natural world—seems to exist independently from historical context. Because scientists are able to prove their ideas through experiments (and because their work so often has real-world applications), it seems unnecessary to introduce any historical complexity or doubt into their research. But Kuhn makes clear that while he sees scientific discoveries as operating within a cycle, "that circularity does not at all invalidate them. But it does make them parts of a theory and, by doing so, subjects them to the same scrutiny regularly applied to theories in other fields." In other words, by acknowledging that their field is cyclical and dependent on context, scientists are forced to think more critically about their work—without at all abandoning it. Moreover, Kuhn's view of scientific history allows each paradigm's questions and findings to remain useful even after the paradigm itself has been abandoned, thereby expanding (instead of narrowing) what counts as scientific knowledge.

PERCEPTION AND TRUTH

Though scientists' work relies on collecting empirical data, Thomas Kuhn's treatise *The Structure of Scientific Revolutions* argues that scientists' views of the world also play an important role, because their perceptions are what dictate which questions they ask and what they focus on in their research or experiments. As Kuhn sees it, each radically new scientific discovery ushers in a new way of perceiving the world—what Kuhn calls a paradigm—that the scientists in a given field agree on. But while Kuhn emphasizes that these paradigms are a useful way to solve problems, he also makes clear that a new paradigm is more like a fundamental shift in perception than an accumulation of knowledge that brings scientists closer to the truth. Kuhn therefore concludes that while scientists may find new ways of looking at new kinds of problems, they will never get closer to objective truth—and that, in fact, no such thing exists.

First, Kuhn shows how perception and belief are necessary in order to make any scientific work possible. Kuhn suggests that "the operations and measurements that a scientist undertakes in the laboratory are not 'the given' of experience but rather 'the collected with difficulty.'" In other words, even to make basic decisions about what to write down from their experiments, scientists must make a great many decisions about what is important or useful. Kuhn argues that there is so much sensory information in the world that approaching it as a truly neutral observer is impossible. Instead, even when scientists believe they are being completely objective, they are in fact choosing to focus their attention on some data points at the expense of others. Crucially, Kuhn then emphasizes how that choice is guided by internal beliefs and values. Rather than depicting science as a collection of objective observations and experiments, Kuhn notes that "an apparently arbitrary element, compounded of personal and historical accident, is always a formative ingredient of the beliefs espoused by a given scientific community at a given time." In other words, in order to decide what kind of questions to ask and techniques to use, scientists must draw on the "personal and historical" context of what is important to them. To illustrate his point, Kuhn draws on the metaphor of a Rorschach test in which there is a piece of paper with an ambiguous drawing on it. When held horizontally, the image on the paper looks like a **bird**, and there is no question about what kind of animal is one the paper. Similarly, when scientists draw on their innate, initial perceptions, they are looking through the world from a certain angle, and so their problems and solutions seem almost inevitable.

Using various moments in scientific history, Kuhn then posits that great discoveries always caused a fundamental shift in scientists' perception of the world. In Kuhn's metaphorical Rorschach test, the drawing initially appeared to be a bird—but when the paper is flipped 90 degrees, it suddenly appears to be an **antelope**. Kuhn argues that the same thing happened in the history of science when, for example, Copernicus's discovery that the sun was at the center of the solar system transformed not only astronomists' work but the very way they perceived the sky around them. That shift in experience, Kuhn explains, is why "paradigm changes do cause scientists to see the world of their research-engagement differently. In so far as their only recourse to that world is through what they see and do, we may want to say that after a [scientific] revolution scientists are responding to a different world." When a bird becomes an antelope, or one's understanding of the solar system is rearranged, the world as scientists perceive it is completely altered. Kuhn has made it clear that scientific engagement with the universe is always perceptual, so when scientific perception shifts, he then argues the universe itself becomes "different." In emphasizing that paradigms are about shifts in perception, Kuhn is also careful to clarify that no one paradigm is better or more truthful than another. In his section on Galileo's view of the pendulum, for example, Kuhn asks, "why did that shift of vision occur? Through Galileo's individual genius, of course. But note that genius does not here manifest itself in more accurate or objective observation of the swinging body. Descriptively, the Aristotelian perception is just as accurate." Though each paradigm involves a different set of perceptions, Kuhn is firm that one is not "more accurate or objective" than the other. Both merely involve different ways of looking at the same exact thing—and because it is impossible for humans to understand anything without looking at it, it is impossible to get a completely neutral observer who could declare whether Galileo's view is better or worse than Aristotle's.

Ultimately, then, Kuhn suggests that all science can offer is new paradigms of perception, not any objective truth. In one of the book's most famous quotations, Kuhn blurs the line between myth and science: "if these out-of-date beliefs are to be called myths, then myths can be produced by the same sorts of methods and held for the same sorts of reasons that now lead to scientific knowledge. If, on the other hand, they are to be called science, then science has included bodies of belief quite incompatible with the ones we hold today." Kuhn's use of the word "myth" is particularly telling in this quotation; myths imply human feelings and narratives, while science suggests objective fact. But while scientists try to dismiss the conclusions of past eras, their own work is similarly dependent on instinct and intuition. Indeed, because all scientific language draws on particular points of focus or underlying beliefs, Kuhn believes that "language thus restricted to reporting a world fully known in advance can produce mere neutral and objective reports on 'the given.'" In other words, no one can look at a pendulum swinging and view it without any lens or beliefs (which would be necessary for a "neutral and objective report"). And because no individual scientist can separate their particular view from what is actually happening, no scientific community will ever be able to articulate what is actually happening.

At the end of his treatise, therefore, Kuhn calls on his readers to "relinquish the notion, implicit or explicit, that changes of paradigm carry scientists and those who learn from them closer and closer to the truth." If science can never be objective, one paradigm will always exclude the very facts that another paradigm holds dear; to put it in terms of Kuhn's own metaphor, the Rorschach drawing can never be both bird and antelope at the same time, even though it contains both within it. Though it is radical, then, Kuhn's final argument makes sense: science will hold great value, but it will never reach a solid, objective truth—perhaps because no such thing exists.

INTUITION AND EMOTION

Science is usually thought of as an objective discipline based on observation, facts, and hard data. Yet in *The Structure of Scientific Revolutions*, historian Thomas Kuhn argues that science is far less logical than it seems. Kuhn believes that each world-altering scientific discovery, from the law of gravity to the theory of relativity, actually begins with intuition—in a "lightning flash" of genius, one scientist's instincts lead them to experience the world in a new way. Moreover, in order for the scientific community to adopt this new theory, Kuhn suggests that they must be persuaded not by rational proof but by aesthetic or emotional appeals. As such, Kuhn refutes the idea that scientists are objective and emotionless and suggests that intuition and feeling are what allow one scientific idea to triumph over another.

First, Kuhn tries to understand the emotional motives behind what he calls normal science: the everyday scientific work of trying to expand and apply a given paradigm to a variety of problems. Scientists are commonly thought to be motivated by "the desire to be useful, the excitement of exploring new territory, the hope of finding order, and the drive to test established knowledge." Kuhn acknowledges that there is some truth to this perception of heroic science, as many young people do become scientists out of idealism. At the same time, he is interested in the more personal impulses that drive scientists (like the "excitement" of being one of few people who can understand a certain field). Kuhn argues that, for the most part, a scientist's day-to-day life is driven by a sense of competition; "if only he is skillful enough, he will succeed in solving a puzzle that no one before has solved or solved so well." Kuhn goes on to comment that normal science requires "a proper sort of addict," one who prioritizes the thrill of solving puzzles and impressing colleagues above all else. Here, Kuhn completely undercuts the classic portrait of the objective, disinterested scientist and instead suggests that scientists are "thrill-seekers," addicted to finding out the answers that elude their colleagues.

Kuhn also describes great, world-changing scientific discoveries—what he calls moments of extraordinary science—as deeply personal and instinctive. For the lone geniuses who engage in extraordinary science, "the new paradigm […] emerges all at once, sometimes in the middle of the night, in the mind of a man deeply immersed in crisis." Kuhn's writing here suggests a deep interest in the interior—even spiritual—lives of scientists. He asks readers to imagine these great thinkers in their private bedrooms in "the middle of the night," not only confronted with a crisis of knowledge but actually "immersed" in it. Interestingly, while science is often understood to be observation-based, Kuhn shifts the focus from these geniuses' "stimuli" to their "sensations." "Very different stimuli can produce the same sensations," Kuhn points out, just as "the same stimulus can produce very different sensations." At its core, then, Kuhn's claim is that scientists rely on lived experience ("sensations") to make their conclusions—and so understanding them as real people with real lives is crucial to understanding their work.

Most importantly, Kuhn argues that the triumph of one scientific idea over another is more about feeling than fact. "The transfer of allegiance from paradigm to paradigm," writes Kuhn, "is a conversion experience that cannot be forced." Again, Kuhn thinks of science as something almost spiritual ("conversion"), one that develops not through logic but through deeply personal realizations. Though these arguments might never be made directly, many scientific theories appeal directly to scientists' sense of what is "aesthetic—the new theory is said to be 'neater,' 'more suitable' or 'simpler' than the old." In other words, theories do not triumph because they are "right" so much as because scientists admire their simplicity or their style. Here, Kuhn's focus on scientists' humanity goes to the heart of his argument—that one idea is not more truthful than another, but rather that it appeals more to a given group of human beings in a given time. Kuhn also compares scientific revolutions to political ones: both rely on the "techniques of mass persuasion," focusing less on logic and more on rhetoric and argumentation. As Kuhn works to humanize individual scientists, he also is fascinated by scientists' relationships with one another, both in terms of large-scale community and small-scale friendships or collaborations. Finally, then, Kuhn concludes that paradigm shifts can happen "not despite the fact that scientists are human but because they are." Because scientists' work is deeply personal, aesthetic, and experiential, they are able to move outside of the rigid bounds of logical problem solving—and to transform their field in the process.

COMMUNITY AND KNOWLEDGE

In *The Structure of Scientific Revolutions*, historian of science Thomas Kuhn argues that many of the most important scientific discoveries are made by individuals. However, these individuals' insights can only be applied in specific, real-world ways when a larger group of scientists learn about them and accept them as fact. Kuhn thus claims that community is essential to scientific work—only when many scientists have similar educations and a shared set of goals can they begin to build on one another's work, collaborating to solve a variety of related problems instead of arguing over basic principles. Furthermore, Kuhn suggests that if scientific knowledge depends on communities to develop and spread, then understanding how scientists communicate and compromise with one another is key to understanding the kind of scientific knowledge they produce.

Kuhn suggests that, perhaps even more than in other disciplines, specific scientific communities are rigidly defined: each member of a community must operate according to the same ideas as the others, and the community is therefore cut off from other communities and the world at large. In order to gain specificity and broad application, a few individuals must adopt and adapt a paradigm, thus making it "attract the allegiance of the scientific community as a whole." This sentence signals one of Kuhn's most subtly radical ideas: because the extraordinary science that produces groundbreaking shifts in science is so grounded in individual perception and belief, community is what transforms this personal insight into a legitimized science. In other words, Kuhn argues that unless the scientific community can agree on an idea, that idea is not considered to be scientific. Kuhn explains that because typical textbook-based scientific education is both "rigorous and rigid," it forces science students to think within the same "conceptual boxes" as their contemporaries. Further, Kuhn argues that the textbooks a scientist reads tacitly define not only specific scientific understanding but also the scientist's general way of perceiving the world. Kuhn explains that because scientists learn their discipline through problem-solving, internalizing ways of scientific thinking without even necessarily being able to explain such ideas, their brains become hardwired to view the world in a certain way. In this way, Kuhn argues, a scientific community shares an internalized set of beliefs. These shared beliefs allow scientists to communicate with each other, but it also shuts them off from the outside world. "Given a textbook," Kuhn writes, a scientist "can begin his research where [the textbook] leaves off and thus concentrate exclusively upon the subtlest and most esoteric aspects of the natural phenomena that concern his group." That scientists' findings will then be addressed to the other scientists "whose knowledge of a shared paradigm can be assumed and who prove to be the only ones able to read the papers." While textbooks give scientists the same tacit set of beliefs, Kuhn explains, the academic essays and research publications provide scientists within a community with a shared—and exclusive—language, one founded on the beliefs of the community's paradigm and inaccessible to those in other communities.

Kuhn explains that although these communities sometimes prevent new discoveries or ideas, they also allow scientists to collaborate with new focus and precision and, in fact, help enable new discoveries. Normal science depends on "the assumption that the scientific community knows what the world is like." To conduct their daily work, scientists have to agree not only with their contemporaries but also with the textbooks and teachers that formed their education. Scientific communities then allow a single worldview to be transmitted not only between individuals but across generations and geographic distance. To prove his point, Kuhn cites a quotation from Francis Bacon, an important 16th-century scientist. "Truth," Bacon writes, "emerges more readily from error than from confusion." Scientists may not always succeed in their individual efforts, but by agreeing with a group of peers on their goals and methods—by eliminating "confusion"—they can at least proceed with a shared sense of purpose. Similarly, even as these communities restrict original thought, they also (even inadvertently) enable novel discoveries. In fact, Kuhn argues that because members of a given scientific community share one another's values, they are able to collectively "identify crisis or, later, choose between incompatible ways of practicing their discipline." Rather than being thrown into a tailspin by every surprising discovery, the ability of scientists' within a community to communicate with one another also allows them to pick and choose which unexpected findings (anomalies) are truly worth focusing on.

In his 1969 postscript to the original text of *The Structure of Scientific Revolutions*, Kuhn made clear his enduring focus on the topic of community: "if this book were being rewritten," he reflects, "it would […] open with a discussion of the community structure of science." In fact, Kuhn ends his postscript with a call for more study of scientific communities (or academic communities as a whole). After all, if communities are necessary for both normal and extraordinary science, understanding how members debate and come to consensus is crucial to understanding how any kind of science is produced.

NORMAL SCIENCE VS. EXTRAORDINARY SCIENCE

Science textbooks present science as an endless process of new discovery. But in *The Structure of Scientific Revolutions*, historian Thomas Kuhn argues that the kind of work most scientists do day-to-day actually discourages novelty and original thinking. Instead, Kuhn suggests that there are two different kinds of science: extraordinary science, in which one individual suddenly conceptualizes the world in a new light, and normal science, which involves trying to "force nature" to conform to their expectations. Extraordinary science leads to new sets of questions and techniques, while normal science involves answering those questions and applying those techniques. Yet rather than dismissing normal science, Kuhn makes a surprising case for its importance: because it eventually forces scientist to face the holes in their beliefs, normal science is what makes extraordinary science possible.

Kuhn argues that day-to-day, normal science is not about new ideas and discoveries—and in fact, normal science actively works to suppress this kind of original thinking. "No part of the aim of normal science is to call forth new sorts of phenomena," writes Kuhn. Instead, Kuhn refers to normal science as "mop-up work," in which scientists apply the rules of their paradigm to a variety of increasingly specific problems—cleaning up the existing ideas without adding any of their own. To illustrate his point, Kuhn compares normal science to a "**jigsaw puzzle**." Completing a jigsaw puzzle is not about imagining a different or more interesting picture; rather, it is putting together the pieces to reform the picture on the puzzle box. Similarly, Kuhn argues that normal science is about providing new examples of familiar conclusions (through experimental data and research). But to continue this kind of puzzle-solving work, normal science must not acknowledge any new guiding rules or concepts. As Kuhn puts it, normal science "often suppresses fundamental novelties" because those novelties undermine the basic ideas of the current paradigm. For the "mop-up work" of normal science to have meaning, the ideas and beliefs that undergird that science must not be changed. For scientists who conduct research and experiments according to the rules of a given paradigm, then, thinking outside the box would actually invalidate the vast majority of their daily work.

On the other hand, extraordinary science, which does involve radically new ideas, has almost nothing to do with the everyday practices of science (such as research and calculation). If Kuhn used the predictable jigsaw puzzle to symbolize normal science, he sees extraordinary science as an unsolved puzzle: "scientists then often speak of the 'scales falling from the eyes' or of the 'lightning flash' that inundates a previously obscure puzzle." Importantly, Kuhn describes the process of extraordinary science with language more often reserved for discussing moments of artistic inspiration. In other words, if normal science is like solving a jigsaw puzzle, extraordinary science is about creating a new picture entirely. And while normal science involves preserving the world as it is, extraordinary science marks such a change in perception that it is a "transformation of the world within which scientific work was done." Because extraordinary science reorients scientists' perspective on the world, it also changes the way their own personal experiences and perceptions.

Ultimately, though normal science and extraordinary science are very different, Kuhn shows that neither type would be possible without the other. Extraordinary science—the invention of a given paradigm—always opens the door to normal science. As Kuhn puts it, "during the period that the paradigm is successful, the profession will have solved problems that its members could scarcely have imagined and would never have undertaken without commitment to the paradigm." Extraordinary science, which provides a set of scientific values and beliefs, is necessary for normal scientists to focus on a small set of questions and to build on one another's work. However, because normal science allows scientists to see the flaws of their paradigm, it also highlights the anomalies any new theorist must consider. For example, X-ray technology was discovered when one physicist, conducting a routine experiment with cathode rays, noticed a glow where he did not expect to see one. Because normal science teaches its practitioners what to look for with great detail and precision, it is much easier to notice the unexpected—and therefore to realize the flaws in a paradigm that lead to the revelation of an entirely new paradigm. This is why scientific theories are also formed with what Kuhn calls a "certain circularity." Extraordinary science makes normal science possible—and then, in turn, normal science, by slowly identifying holes in the current paradigm, creates the need for extraordinary science. Therefore, even as Kuhn draws a distinction between the two types of science, he does not suggest that either one is better than the other; in fact, he suggests that they are both necessary parts of scientific discovery.

SYMBOLS

Symbols appear in **teal text** throughout the Summary and Analysis sections of this LitChart.

JIGSAW PUZZLES

Kuhn uses jigsaw puzzles as a symbol for the process of normal science. Jigsaw puzzles (like normal science) have a set of rules "that limit both the nature of acceptable solutions and the steps by which they are to be obtained." In other words, the point of a jigsaw puzzle is to mimic the picture on the box, not to create a new picture. Similarly, the point of normal science is to apply a given paradigm in a predictable way, not to make a new discovery. Both jigsaw puzzles and normal science are about arriving at a pre-set solution in inventive ways. Moreover, Kuhn argues that scientists who engage in normal science (which is the vast majority of scientists) are doing so for the same reasons other people might do a crossword or solve a jigsaw puzzle—rather than trying to help humanity or see the world in a new way, these scientists are motivated by the idea that they can "succeed in solving a puzzle that no one before has solved or solved so well."

BIRD/ANTELOPE

The bird/antelope drawing, a classic Rorschach test, symbolizes paradigm shifts in science. When the piece of paper with the drawing on it is held horizontally, the drawing appears to be of a bird; when it is held vertically, the drawing appears to be of an antelope (another example of this that Kuhn uses is the duck/rabbit drawing). To Kuhn, this rotation of the paper symbolizes how a scientist going through a paradigm shift "sees differently from the way he had seen before." Just as a someone looking at the bird/antelope drawing vertically perceives a different picture, Kuhn argues that after a scientific revolution, "scientists are responding to a different world." However, while these Rorschach tests are reversible (one can always flip the paper back to its original orientation), Kuhn is careful to note that the same is not true for paradigm shifts. Once scientists have perceived the world in a new light, they believe that in order for the new paradigm to make sense, all their previous perceptions had to have been mistakes.

QUOTES

Note: all page numbers for the quotes below refer to the University of Chicago Press edition of *The Structure of Scientific Revolutions* published in 2012.

Chapter 1 Quotes

History, if viewed as a repository for more than anecdote or chronology, could produce a decisive transformation in the image of science by which we are now possessed.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 1

Explanation and Analysis

In this very first sentence of his book, Kuhn lays out his goal: he wants not only to detail the history of certain discoveries but also to transform how people understand science as a whole. But if he is trying to change his readers' view of science, Kuhn is also interested in writing a new kind of history—one that alters his audience's understanding of the world instead of merely describing it.

Even from its opening paragraph, then, *The Structure of Scientific Revolutions* has a kind of twofold mission. On the one hand, the book walks through various thought revolutions in science, where one set of beliefs and questions is replaced by another; on the other hand, the book tries to *create* a thought revolution in history. As Kuhn continues with his argument, it is important to track the parallel between Kuhn's own project and the scientific discoveries he writes about.

If these out-of-date beliefs are to be called myths, then myths can be produced by the same sorts of methods and held for the same sorts of reasons that now lead to scientific knowledge. If, on the other hand, they are to be called science, then science has included bodies of belief quite incompatible with the ones we hold today.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 3

Explanation and Analysis

In one of the book's most famous lines, Kuhn calls attention to now-discredited scientific frameworks (which he calls paradigms). Though contemporary scientists now view many of these paradigms as superstitious or silly, in their own time, these paradigms were predictive, precise, and popular. Earlier scientists were no less observant or methodical, and as Kuhn points out, people living in the 17th century viewed their science with just as much certainty and pride as people living today.

But if these past paradigms were disproved and abandoned, what is to stop today's science from falling prey to the same fate? Kuhn argues that ultimately, modern science is just as much a "body of belief" as the scientific practices that have come before it—and therefore is just as likely to be discredited. Rather than depicting science as a linear march toward progress, then, Kuhn depicts the history of science as a clash of "incompatible" worldviews, with no one idea emerging as more valid or correct than the ones before it.

It is also worth paying close attention to Kuhn's use of the word "myth." On the one hand, this word implies that the gap between science and truth is much larger than it seems; if science is a myth, it is an invented narrative, not objective fact. But on the other hand, the use of the word myth suggests that there is a degree of human creation and artistry involved in scientific practice. And indeed, Kuhn will continue to argue for blurring the lines between science and art.

Chapter 2 Quotes

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. If that body of belief is not already implicit in the collection of facts—in which case more than "mere facts" are at hand—it must be externally supplied, perhaps by a current metaphysic, by another science, or by personal and historical accident. No wonder, then, that in the early stages of the development of any science different men confronting the same range of phenomena, but not usually all the same particular phenomena, describe and interpret them in different ways.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 17

Explanation and Analysis

In his efforts to counter the simplified history of science textbooks, Kuhn begins with the practice of observation, so often portrayed in textbooks as neutral and judgment-free. Kuhn, however, claims that in any given moment, great quantities of information are available, so scientists must pick which data points to study. Choosing where to focus then involves choices—and to make those choices, scientists must draw on their own beliefs, whether those beliefs are "personal" or "historical" (grounded in their community's context and priorities). Even the most seemingly basic activity of observation is therefore also shaped by scientists' own biases and beliefs.

This passage also begins to highlight the difficulty of scientific communication in the absence of a unifying paradigm. If two scientists can look at the same phenomenon and experience it two dramatically different ways, then it is almost impossible to agree on the events worth studying, much less how those events might fit together. The difficulty of this communication (what Kuhn will later label the "incommensurability" of different paradigms) is an important theme throughout the book.

Chapter 3 Quotes

Mopping-up operations are what engage most scientists throughout their careers. They constitute what I am here calling normal science. Closely examined, whether historically or in the contemporary laboratory, that enterprise seems an attempt to force nature into the preformed and relatively inflexible box that the paradigm supplies. No part of the aim of normal science is to call forth new sorts of phenomena; indeed those that will not fit the box are often not seen at all.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 24

Explanation and Analysis

As Kuhn begins to get into the nuts and bolts of his theory, he coins the term normal science—the daily practice of research and experiment, in which scientists work not to discover new things but to prove, expand, and apply the existing paradigm. Kuhn's use of the term "mopping up" is particularly useful: just as people mop the floors in their homes to maintain the neat, pleasant status quo, normal science works not to move forward but to preserve current ideas exactly as they are. Kuhn is thus reframing scientific work in quite a radical way, suggesting that the everyday practice of science is much less glamorous and more ideologically motivated than it seems.

Equally important is Kuhn's assertion that science "force[s] nature" into the box provided by theory; in other words, normal science actively shapes the world rather than passively responding to it. In fact, when scientists are confronted with gaps between theory and nature, they are more likely to try to change or "not see" nature than to alter the theory. In this passage, then, Kuhn begins to suggest that science is highly subjective, even though the field is so often associated with objective truth.

Chapter 4 Quotes

Once engaged, his motivation is of a rather different sort. What then challenges him is the conviction that, if only he is skillful enough, he will succeed in solving a puzzle that no one before has solved or solved so well. Many of the greatest scientific minds have devoted all of their professional attention to demanding puzzles of this sort. On most occasions any particular field of specialization offers nothing else to do, a fact that makes it no less fascinating to the proper sort of addict.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 38

Explanation and Analysis

Scientists are so often portrayed as disinterested, removed observers, but here—and throughout *The Structure of Scientific Revolutions*—Kuhn is careful to emphasize the human, psychological motives that drive the everyday practice of science. Rather than seeking purely for a deeper understanding, scientists are also driven by more familiar thrills. Kuhn compares normal scientific successes to the satisfaction people get from completing crossword puzzles; he emphasizes the degree of competition that pushes scientists to work smarter and faster than their colleagues.

In addition to exploring the "addictive" nature of this puzzle-solving, Kuhn gestures here to the community structure of science. For much of the book, he argues that agreement is a key facet of scientific progress—but in this passage, he suggests that agreement on the basic facts also allows scientists to race against one another for the most satisfying answers. In other words, no game is fun unless other people are playing by the same rules.

> There must also be rules that limit both the nature of acceptable solutions and the steps by which they are to be obtained. To solve a jigsaw puzzle is not, for example, merely "to make a picture." Either a child or a contemporary artist could do that by scattering selected pieces, as abstract shapes, upon some neutral ground. The picture thus produced might be far better, and would certainly be more original, than the one from which the puzzle had been made. Nevertheless, such a picture would not be a solution. To achieve that all the pieces must be used, their plain sides must be turned down, and they must be interlocked without forcing until no holes remain.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Related Symbols:

Page Number: 38

Explanation and Analysis

As Kuhn tries to reshape his readers' view of scientists' day-to-day practice, he lands on the jigsaw puzzle as an extremely useful metaphor for the work of normal science. The picture that emerges at the end of the jigsaw puzzle is printed on the box; there is no real novelty or surprise in completing such a picture. Instead, the fun lies not in the discovery but in the process, and in the puzzle-solver's speed or cleverness when it comes to fitting the pieces together. The same could be said of normal science: scientists engaged in this kind of research certainly need skill and education, but they are fundamentally trying to arrive at a familiar picture of the world (as laid out by the paradigm).

Interestingly, Kuhn mentions that "either a child or a contemporary artist" could throw the puzzle pieces into a new form entirely, creating a new—and perhaps "better"—picture. Implicitly, then, Kuhn is contrasting the puzzle-work of normal science with the artistry of paradigm creation, in which scientists begin to the view world in novel, more "original" ways. Though Kuhn does not articulate this comparison directly, it is important to notice. Later on, Kuhn will call for scientists to think more like artists in the way they approach their surroundings, acknowledging that their ideas are human inventions and not inherent in their environment.

Chapter 5 Quotes

> That process of learning by finger exercise or by doing continues throughout the process of professional initiation [...] One is at liberty to suppose that somewhere along the way the scientist has intuitively abstracted rules of the game for himself, but there is little reason to believe it. Though many scientists talk easily and well about the particular individual hypotheses that underlie a concrete piece of current research, they are little better than laymen at characterizing the established bases of their field, its legitimate problems and methods.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 47

Explanation and Analysis

Kuhn has already explored the way science textbooks simplify historical narratives, but in this passage, he turns his attention to the other major way textbooks shape young scientists' thought: by emphasizing problem-solving over conceptual explanation. Rather than dwelling on the underlying beliefs and perspectives that created a paradigm, most textbooks introduce a few rules and key equations and then expect students to apply these basics to a variety of real-life situations.

Kuhn argues that in using "finger exercises" more than written explanations, textbooks are training their students to internalize a paradigm's specific worldview as fact. This allows for effective normal science, as students are never asked to question—or even fully understand—the "established" beliefs of their paradigm. Kuhn thus shows how the creative, ideological work of paradigm creation becomes the day-to-day, unquestioned work of normal science.

In his postscript to the original publication, Kuhn will label this kind of learning "tacit knowledge": through textbook problems, students learn to see the world in a certain way without ever being able to articulate the shift in their perception. More than anything else, Kuhn argues in his postscript, this shared "tacit knowledge" is what bands various members of a scientific community together, as it defines a paradigm not through language but through practical applications.

An investigator who hoped to learn something about what scientists took the atomic theory to be asked a distinguished physicist and an eminent chemist whether a single atom of helium was or was not a molecule. Both answered without hesitation, but their answers were not the same. For the chemist the atom of helium was a molecule because it behaved like one with respect to the kinetic theory of gases. For the physicist, on the other hand, the helium atom was not a molecule because it displayed no molecular spectrum. Presumably both men were talking of the same particle, but they were viewing it through their own research training and practice. Their experience in problem-solving told them what a molecule must be.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 51

Explanation and Analysis

To illustrate just how much paradigms shape scientists' views, Kuhn shares this startling anecdote (initially relayed to him by friend and colleague James K. Senior). The physicist and chemist in Kuhn's story were both experts in their fields, and for both men, a thorough knowledge of atomic theory was essential to their daily work. But in order to do their work, each man had to adopt a radically opposing understanding of one of the central questions of atomic theory: what constitutes a molecule? In other words, each man's paradigm looked at the same situations through a different lens.

Neither scientist's view was more accurate than the other's; both scientists used their beliefs to conduct their everyday practice of normal science successfully. What this anecdote points to, then, is the necessity of scientific interpretation—and the absence of purely objective truth. And while the physicist and chemist in question disagreed because they came from two different disciplines, Kuhn's larger project is to show how these clashing perspectives occur not only across disciplines but across time. Just as both the physicist and the chemist have valid worldviews, Kuhn argues that a physicist in the 15th century had just as much to offer science as a physicist today does.

Chapter 6 Quotes

New and unsuspected phenomena are, however, repeatedly uncovered by scientific research, and radical new theories have again and again been invented by scientists. […] If this characteristic of science is to be reconciled with what has already been said, then research under a paradigm must be a particularly effective way of inducing paradigm change. That is what fundamental novelties of fact and theory do. Produced inadvertently by a game played under one set of rules, their assimilation requires the elaboration of another set.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 53

Explanation and Analysis

One of Kuhn's most radical claims is that the history of science moves in a circular pattern, not in a straight line toward progress. Normal science leads to a period of crisis, which leads to a new paradigm, which in turn lays the foundation for a new kind of normal science. Here, Kuhn begins to explain why this pattern repeats itself over and over again—namely, because normal science always reveals its own flaws, pushing scientists to doubt the paradigm they were educated on. The more scientists do research, the more likely they are to stumble on "facts" that they cannot make fit into their theories. And once a paradigm's basic beliefs have been shaken, normal science's aversion to novelty gives way to a desire for brand-new thought.

It is also important to note Kuhn's use of the word "game" here: again, he is painting normal scientists as puzzle-solvers, concerned less with discovery and more with using a "set of rules" to compete against their colleagues. Yet rather than critiquing this "game" mentality, Kuhn shows how these rules and competitions are an essential precursor to groundbreaking scientific discovery.

Anomaly appears only against the background provided by the paradigm. The more precise and far-reaching that paradigm is, the more sensitive an indicator it provides of anomaly and hence of an occasion for paradigm change.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 65

Explanation and Analysis

Here, Kuhn dives further into the paradox of a successful paradigm. When a paradigm is compelling enough, a great deal of scientific works is done to test and apply the paradigm. And since some paradigms prevail for centuries, many disciplines reach a point where individual scientists know exactly what to expect, on a minute level of detail, from any given experiment. But it is precisely because scientists know just what to expect that they notice when some fact or observation is even slightly different—"anomalous," in Kuhn's language—from what the paradigm predicts.

New, less-advanced paradigms have far fewer expectations, and so are far less likely to be overturned than long-established, precise paradigms. In other words, the more developed and precise a paradigm is, the more "sensitive" scientists are to surprises. Thus normal science, in trying to preserve a given paradigm, inadvertently also builds toward that paradigm's collapse—and the cyclical pattern of scientific discovery is bound to repeat itself.

Chapter 7 Quotes

Philosophers of science have repeatedly demonstrated that more than one theoretical construction can always be placed upon a given collection of data. History of science indicates that, particularly in the early developmental stages of a new paradigm, it is not even very difficult to invent such alternates. But that invention of alternates is just what scientists seldom undertake [...] The reason is clear. As in manufacture so in science—retooling is an extravagance to be reserved for the occasion that demands it. The significance of crises is the indication they provide that an occasion for retooling has arrived.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 76

Explanation and Analysis

Kuhn uses the word "crisis" to describe the collapse of an established paradigm. But as this passage makes clear, such a word is far from melodramatic. Instead, Kuhn demonstrates that even though it is relatively easy for scientists to invent new core lenses through which to view their field, there is no reason for them to do so—unless they absolutely have to. True crisis, in which scientists cannot agree with one another or trust their own perceptions, is therefore the only way to prompt what would otherwise be relatively simple "alternate" ideas.

It is not necessarily "very difficult" for scientists to invent new paradigms, but much of paradigms' appeal comes from the fact that they provide certainty, clarity, and a sense that scientists can understand the world in which the work. Kuhn's emphasis on these "crises" in belief then also implies the extent to which scientists have a kind of spiritual faith in their work; to have that work questioned introduces not only academic debate but personal doubt. That is why Kuhn claims it is always an "extravagance" to leap to a new worldview, a new paradigm: in admitting they were wrong about their work, scientists—whose job it is to understand the world—are also admitting to being wrong about the universe they inhabit.

Chapter 8 Quotes

When acute, this situation is sometimes recognized by the scientists involved. Copernicus complained that in his day astronomers were so "inconsistent in these [astronomical] investigations . . . that they cannot even explain or observe the constant length of the seasonal year." "With them," he continued, "it is as though an artist were to gather the hands, feet, head and other members for his images from diverse models, each part excellently drawn, but not related to a single body, and since they in no way match each other, the result would be monster rather than man." Einstein, restricted by current usage to less florid language, wrote only, "It was as if the ground had been pulled out from under one, with no firm foundation to be seen anywhere, upon which one could have built."

Related Characters: Thomas Kuhn (speaker), Nicolaus Copernicus, Albert Einstein

Related Themes:

Related Symbols:

Page Number: 83

Explanation and Analysis

To demonstrate just how profoundly anomalies affect scientists, Kuhn relies on testimony from two such scientists themselves: Nicolaus Copernicus, who discovered that Earth rotated around the sun (and not the other way around), and Albert Einstein, who linked space to time with his theory of relativity. Copernicus's statement demonstrates the difficulty of maintaining scientific community in moments of crisis: if normal science is usually a jigsaw puzzle, by Copernicus' time, the puzzle pieces of astronomy "in no way match[ed] each other," and scientists were struggling to recreate a picture that no longer cohered.

Copernicus therefore makes clear the impossibility of collaborating when the central image or paradigm has lost its initial clarity. Moreover, without this collaboration between scientists, no progress can be made on real-world applications; the "inconsisten[cy]" that Copernicus observes in astronomers' beliefs is then directly reflected in the increasingly unworkable calendar.

On the one hand, Copernicus's quotation shows how scientific crises fracture communities, making scientists' day-to-day work almost impossible. On the other hand, Einstein speaks to the profound individual effects of such a crisis. Kuhn will later argue that paradigm shifts dramatically alter not only scientists' professional lives but also their lived experiences. Here, Einstein testifies to that shift first-hand: without clear scientific moorings, his world collapsed around him, leaving him feeling "as if the ground had been pulled out from under" him.

The marks on paper that were first seen as a bird are now seen as an antelope, or vice versa. That parallel can be misleading. [...] the scientist does not preserve the gestalt subject's freedom to switch back and forth between ways of seeing. Nevertheless, the switch of gestalt, particularly because it is today so familiar, is a useful elementary prototype for what occurs in full-scale paradigm shift.

Related Characters: Thomas Kuhn (speaker), Aristotle, Galileo Galilei

Related Themes:

Related Symbols:

Page Number: 85

Explanation and Analysis

If the jigsaw puzzle is a useful symbol for normal science, Kuhn's gestalt drawing (also commonly called a Rorschach test) is a perfect tool to make sense of a paradigm shift. Held horizontally, some squiggles on a piece of paper might look quite clearly like a bird; but if one flips that same paper vertically, and all of a sudden, the very same squiggles become an antelope.

That change in vision—that new "gestalt," or angle from which to view the world—is a crucial part of a paradigm shift. For example, Kuhn discusses how Aristotle and Galileo could look at a pendulum and come to dramatically conclusions about how that pendulum worked, even though they were looking at the same object and the same process. But Galileo was able to metaphorically flip the paper in his scientific work: he looked at the pendulum in a new light (as a swinging body), and then he used that new lens to invent his own theories of motion.

It is also worth noting Kuhn's insistence that while it is easy to flip the drawing of the antelope back to its original orientation, again making it a drawing of a bird, the same is not possible in a scientific paradigm shift. As Kuhn has earlier asserted, normal science depends on scientists' belief that their worldview is the correct, factual one. To try to see the drawing as a bird—or to try, post-Galileo, to view the world through Aristotelian physics—would be to acknowledge the arbitrariness of the current paradigm, and therefore to discount the normal science that comes out of it.

Instead, the new paradigm, or a sufficient hint to permit later articulation, emerges all at once, sometimes in the middle of the night, in the mind of a man deeply immersed in crisis. [...] Almost always the men who achieve these fundamental inventions of a new paradigm have been either very young or very new to the field whose paradigm they change. And perhaps that point need not have been made explicit, for obviously these are the men who, being little committed by prior practice to the traditional rules of normal science, are particularly likely to see that those rules no longer define a playable game and to conceive another set that can replace them.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 90

Explanation and Analysis

Though Kuhn begins his discussion with an emphasis on the puzzle-solving nature of normal scientists, he turns here to the character of extraordinary scientists. Rather than working slowly and methodically according to a set of rules, extraordinary scientists work more like artists, converting personal "crisis" into lightning-bolt, "middle of the night" insight. If normal science prioritizes logic, extraordinary science prizes intuition and creativity; if normal science requires experience, extraordinary science is best practiced by those who are "very young" or at least less familiar with a paradigm's basics.

In addition to revealing the unique traits of an extraordinary scientist, this passage also makes a subtler point about scientific community. The communities that work together on normal science thrive on compromise and collaboration; even if individuals are competing with one another, they are all playing the same "game." So, even though Kuhn emphasizes the necessity of scientific communities, he also notes that those communities are stifling of new thought. In other words, if paradigms are preserved by a group of scientists working in a pack, truly novel discovery comes from some lone person on the outside.

Chapter 9 Quotes

❝❝ As in political revolutions, so in paradigm choice—there is no standard higher than the assent of the relevant community.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 94

Explanation and Analysis

Kuhn is always deeply intentional in his word choice, and his use of word "revolution"—a word that appears in his book's title—is no exception. In political history, revolutions are social movements: a group of people decide that their values and priorities no longer line up with their government's actions, and this disagreement prompts them to rebel. Textbooks present the story of scientific progress as a linear one, driven not by value judgments but by neutral observations. But Kuhn contests that narrative, asserting that scientific revolutions are driven just as much by a community's desire for change as political revolutions are.

Importantly, if political revolutions happen because a community no longer believes in their government's actions, then moments of scientific peace—as in, the day-to-day work of normal science—happen because a community "assents" to a shared set of beliefs and perspectives. Just as governments can only exist so long as a large group of people agree to be governed, scientific paradigms depend on community acceptance; one individual might have a great idea, but unless they can convince a group of experts to agree with and test out their idea, it will not be considered "science." While textbooks depict science as an objective, impersonal field, Kuhn suggests that science is actually just as reliant on democracy and community as any government in the world.

❝❝ What occurred was neither a decline nor a raising of standards, but simply a change demanded by the adoption of a new paradigm. Furthermore, that change has since been reversed and could be again. In the twentieth century Einstein succeeded in explaining gravitational attractions, and that explanation has returned science to a set of canons and problems that are, in this particular respect, more like those of Newton's predecessors than of his successors.

Related Characters: Thomas Kuhn (speaker), Isaac Newton, Albert Einstein, Nicolaus Copernicus, Aristotle

Related Themes:

Page Number: 108

Explanation and Analysis

Throughout *The Structure of Scientific Revolutions*, Kuhn demonstrates that each individual paradigm goes through a sort of life cycle, from invention to application to crisis. But here, he suggests that even viewed as a whole, a given discipline's trajectory is more circular than linear. Because each paradigm involves a radically different perspective than the one before, it is not unlikely that a given paradigm might resemble the science of 300 years ago more than it resembles the theories of a decade ago.

This quote about Einstein's theory, which looked more like pre-Newtonian physics than the more contemporary post-Newtonian physics Einstein was raised on, helps to illustrate that claim. But there are many examples of this kind of reversion throughout the text. Copernicus's heliocentric vision of the universe mirrors the ancient Greek theory from Aristarchus, who similarly believed that Earth rotated around the sun. And in pioneering the idea of gravity as a built-in property of moving objects, Isaac Newton himself returned to a more Aristotelian view of the world that had long been dismissed as occult.

Chapter 10 Quotes

Examining the record of past research from the vantage of contemporary historiography, the historian of science may be tempted to exclaim that when paradigms change, the world itself changes with them. Led by a new paradigm, scientists adopt new instruments and look in new places. Even more important, during revolutions scientists see new and different things when looking with familiar instruments in places they have looked before. [...] In so far as their only recourse to that world is through what they see and do, we may want to say that after a revolution scientists are responding to a different world.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 111

Explanation and Analysis

For much of his book, Kuhn has hinted at the personal, everyday implications scientific revolutions have for the scientists who live through them. In this passage, Kuhn specifies why scientific revolutions are just as life-altering as political ones; just as a change in governments has profound effects on citizens' daily lives, Kuhn argues that "when paradigms change, the world changes with them."

On the one hand, a paradigm shift makes scientists rethink even the tools and techniques they use most routinely—as Kuhn puts it, scientists start to "see new and different things when looking with familiar instruments in places they have looked before." To exemplify such a shift, Kuhn notes that after X-ray technology was discovered through an anomaly in a cathode ray experiment, apparatuses initially meant to test for these rays suddenly had to be completely rethought.

On the other hand, though, because science is the study of the natural world, when scientists are forced to change their scientific lens, they also must look at their surroundings in a new light. And because scientists work to discover how the universe is, a change in science changes the universe scientists live in. It's no wonder, then, that scientific crises have such profound impacts on scientists both as people and as professionals.

Looking at the moon, the convert to Copernicanism does not say, "I used to see a planet, but now I see a satellite." That locution would imply a sense in which the Ptolemaic system had once been correct. Instead, a convert to the new astronomy says, "I once took the moon to be (or saw the moon as) a planet, but I was mistaken."

Related Characters: Thomas Kuhn (speaker), Nicolaus Copernicus

Related Themes:

Page Number: 115

Explanation and Analysis

Here, Kuhn articulates how the authentic experience of paradigm shift—in which scientists choose one arbitrary set of beliefs over another—is converted into the linear, simplistic narrative presented by textbooks. To admit that a past model "had once been correct," scientists would need to admit that their own paradigm could one day be similarly discounted. Instead, scientists must dismiss their past beliefs as mistaken rather than risk reckoning with the fact that science may never arrive at one stable, objective conclusion.

As Kuhn has earlier discussed, some engineers use the Ptolemaic model of the universe even to this day; this fact again suggests that each paradigm offers its own kind of value. But Kuhn suggests that while scientists are willing to own up to individual change and failure, they will not acknowledge that each paradigm is a valid as any other. Nor will practicing normal scientists admit to the core of Kuhn's argument: that if one's experience of the world is always shaped by belief, then changes in belief to some extent change the world itself. In order to continue with their daily work, scientists must find certainty where there is none, and so Kuhn's complex, cyclical narrative is flattened into a simple line.

But is sensory experience fixed and neutral? Are theories simply manmade interpretations of given data? The epistemological viewpoint that has most often guided Western philosophy for three centuries dictates an immediate and unequivocal, Yes! In the absence of a developed alternative, I find it impossible to relinquish entirely that viewpoint. Yet it no longer functions effectively, and the attempts to make it do so through the introduction of a neutral language of observations now seem to me hopeless. The operations and measurements that a scientist undertakes in the laboratory are not "the given" of experience but rather "the collected with difficulty."

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 126

Explanation and Analysis

Kuhn has consistently emphasized that contemporary science is, to some extent, subjective and "arbitrary." But as he nears the end of his book, Kuhn takes this idea further: instead of arguing merely that science is based in belief, Kuhn now begins to claim that a "fixed and neutral" view of the world is impossible. This is especially radical because it flies in the face of centuries of "Western epistemology" (or the study of knowledge), which dictated that anyone who could patiently observe their surrounds could arrive at an unbiased understanding of them.

The most crucial idea in this passage, however, is that no observation is ever a "given"; any time scientists are jotting down thoughts about what they see, they are making judgment calls grounded in their own personal and historical circumstances. If Kuhn has consistently argued that great scientific shifts are about intuition, here he makes clear that even the most basic lab experiment is also colored by "difficult" decisions about what is most worthy of study.

Chemists could not, therefore, simply accept Dalton's theory on the evidence, for much of that was still negative. Instead, even after accepting the theory, they had still to beat nature into line, a process which, in the event, took almost another generation. When it was done, even the percentage composition of well-known compounds was different. The data themselves had changed. That is the last of the senses in which we may want to say that after a revolution scientists work in a different world.

Related Characters: Thomas Kuhn (speaker), John Dalton

Related Themes:

Page Number: 134

Explanation and Analysis

To give a real-world example of how paradigms reshape the world they aim to describe, Kuhn cites John Dalton's concept of atomic theory, which stated that all molecules combined in whole number ratios (as in, H2O has two hydrogen molecules for every one oxygen molecule). In his own time, Dalton's theory actually flew in the face of experimental data. But Dalton's theory prompted new experiments, new technologies and new techniques—and gradually, experimental data began to match his predictions. In other words, Dalton started with an idea, and "the data themselves" caught up later—in direct contradiction to the observation-based model of science held up by so many textbooks.

Fascinatingly, Kuhn's description of the data following the paradigm relies on quite violent language: here, he writes that scientists had to "beat nature into line," just has earlier he has written that normal science tries to "force nature" into a box. This language of physical force is one more way in which Kuhn draws a parallel between scientific revolutions and political revolutions, so often bloody. And fascinatingly, one of Kuhn's most famous quotes about *The Structure of Scientific Revolutions* emphasizes exactly that kind of (metaphorical) scientific force: the history of science, he would say, is "a series of peaceful interludes punctuated by intellectually violent revolutions."

Chapter 11 Quotes

But scientists are more affected by the temptation to rewrite history, partly because the results of scientific research show no obvious dependence upon the historical context of the inquiry, and partly because, except during crisis and revolution, the scientist's contemporary position seems so secure. More historical detail, whether of science's present or of its past, or more responsibility to the historical details that are presented, could only give artificial status to human idiosyncrasy, error, and confusion. Why dignify what science's best and most persistent efforts have made it possible to discard?

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 138

Explanation and Analysis

In this aptly titled chapter, Kuhn works to understand why scientific revolutions disappear from the historical record while political revolts merit intense historical attention. Kuhn here suggests that while political regimes use history to legitimize themselves, scientists feel "so secure" in their work that they feel no need to do so. After all, why should scientists turn to history to prove their worth when their work so often has tangible results (whether that is new calendars, new medicines, or new machines)?

There is another important thread in this passage, as well: Kuhn is describing the process by which science tries to dehumanize itself, erasing the "idiosyncrasy, error, and confusion" that is, in fact, a very real part of its history. To admit that other eras and paradigms had valuable conclusions is to acknowledge either that scientists can make mistakes or that the world is fundamentally unknowable. If governments use history to make themselves more tangible and connected to the populace, science tries to disconnect itself from context, asserting a certainty that—at least Kuhn would argue—is actually impossible to find.

Finally, it is important to note that Kuhn (once more) brings himself as into his book as a sort of character. Here, in a passage about the difficulty of communication, he admits his own inability to articulate or "explain" himself. Again, Kuhn is invested in showing himself as a flawed, human person as well as a thinker; again, he is drawing a subtle parallel between his own work as a historian and the scientific work he is describing.

Chapter 12 Quotes

❝ These examples point to the third and most fundamental aspect of the incommensurability of competing paradigms. In a sense that I am unable to explicate further, the proponents of competing paradigms practice their trades in different worlds. One contains constrained bodies that fall slowly, the other pendulums that repeat their motions again and again. In one, solutions are compounds, in the other mixtures. One is embedded in a flat, the other in a curved, matrix of space.

Related Characters: Thomas Kuhn (speaker), Aristotle, Galileo Galilei, John Dalton, Albert Einstein, Isaac Newton

Related Themes:

Page Number: 150

Explanation and Analysis

Kuhn has explored at length how paradigms shape and reshape the world in their wake—so it is only logical, then, that scientists operating under one paradigm or perspective struggle to understand scientists effectively functioning in a different universe. As Kuhn points out elsewhere, even when these scientists share some of the same vocabulary, the words mean different things; similarly, even though some experts might use identical machines, those machines might work differently and prove opposite things to people in conflicting paradigms.

One detail worth emphasizing in this passage is Kuhn's use of specific examples. He cites pendulum motion, in which Aristotle's view of "constrained bodies" contrasted with Galileo's idea of "swinging bodies"; he juxtaposes pre-Daltonian chemistry, which accepted most substances as mixtures, with post-Daltonian atomic theory; and he contrasts Newtonian physics with Einstein's more complex, "curved" world. In each of these cases, the building blocks of life and experience are different—as Kuhn explains, the textures of the world are different.

❝ Though a generation is sometimes required to effect the change, scientific communities have again and again been converted to new paradigms. Furthermore, these conversions occur not despite the fact that scientists are human but because they are.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 152

Explanation and Analysis

As he brings his argument to a close, Kuhn turns his attention to the ways in which scientists ultimately do accept new paradigms. Through effective persuasion and through community pressure, large groups of experts are able to give up even their most deeply held beliefs. There are two important things to note in Kuhn's description of this shift: the first is that here and elsewhere, he describes this shift as a "conversion," testifying both to the deeply personal and almost spiritual nature of such a change.

But even more strikingly, Kuhn—who has spent much of his book pointing out all the ways in which scientists are human—now celebrates that humanity. In other words, if scientists were truly as logical and removed as they paint themselves to be, no paradigm shifts (no "conversions") could ever occur; faced with a breakdown in their belief systems, scientists would have no empathy or willingness to listen to one another, and science as a whole might collapse. Thus, even as scientists' humanity ensures that science will always remain to some extent subjective and unreliable, it also allows for new discoveries and new consensus.

Chapter 13 Quotes

❝ We may, to be more precise, 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.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 170

Explanation and Analysis

Kuhn has long argued against the linear scientific history presented by textbooks, but right the end of his original manuscript, he makes his most radical claim yet: scientific progress is not getting closer to any objective "truth," and moreover, that there is no way to access such a truth. Though this argument has been implied throughout the book, here Kuhn directly states the end result of his project: more than adding complexity to the history of science, he is chipping away at the idea that there will ever be any stable, reliable truth for scientists to arrive at.

This claim is especially earth-shattering given one of Kuhn's other points. For much of *The Structure of Scientific Revolutions*, Kuhn has restated the common perception that out of every discipline, science is the one most associated with objectivity and certainty. In other words, if scientists cannot arrive at a stable truth, it is unlikely that anybody can. Kuhn thus claims that no one, scientist or not, will ever be able to know what the world is really like. Instead, bias and belief will always play a role in how scientists (and the laymen who learn from them) make sense of their surroundings. It's no wonder, then, that Kuhn links science more closely to art—both fields help to create the world, yet neither can ever totally capture it.

Postscript Quotes

The law-sketch, say $f = ma$, has functioned as a tool, informing the student what similarities to look for, signaling the gestalt in which the situation is to be seen [...] After he has completed a certain number, which may vary widely from one individual to the next, he views the situations that confront him as a scientist in the same gestalt as other members of his specialists' group. For him they are no longer the same situations he had encountered when his training began. He has meanwhile assimilated a time-tested and group-licensed way of seeing.

Related Characters: Thomas Kuhn (speaker)

Related Themes:

Page Number: 189

Explanation and Analysis

In 1969 postscript, Kuhn tries to clarify and specify several of the claims he had in his initial book, published seven years earlier. More than anything, though, Kuhn focuses on what he labels "tacit knowledge," or the means by which textbooks train students to think in terms of paradigms they do not fully understand (what he has earlier called "finger exercises"). By asking students to solve problems and use certain equations, textbooks shift these young scientists' worldviews—their gestalts—without even giving language to this shift.

In this postscript (and specifically in this passage), Kuhn argues that this kind of problem solving is, more than anything else, the glue that bonds scientific communities together. In particular, he shows here how textbooks allow for continuity from one generation of a paradigm to the next. Without ever having to articulate (or even consciously be aware of) what they are doing, older scientists can share this "time-tested and group-licensed" view with their younger counterparts.

SUMMARY AND ANALYSIS

The color-coded icons under each analysis entry make it easy to track where the themes occur most prominently throughout the work. Each icon corresponds to one of the themes explained in the Themes section of this LitChart.

CHAPTER 1. INTRODUCTION: A ROLE FOR HISTORY

Kuhn lays out the aim of his book: he wants to use history to change the way science is viewed and understood. In particular, he hopes to counteract the simplistic narrative that scientific textbooks present. Kuhn argues that these textbooks tell a linear—and misleading—history of progress, in which scientists move away from error and toward a correct set of tools, techniques and concept.

Right away, Kuhn introduces two key elements of his argument: first, he is pushing back against a dominant narrative of scientific progress, which suggests that scientific discovery moves in a straight line toward truth. Second, he suggests that as a historian, he has an active role in shaping how science is viewed. As the book continues, it is important to remember that Kuhn is always trying to shift the way scientists, historians, and philosophers think.

Recently, historians have been finding it difficult to write this kind of textbook history. For one, scientific discovery is not always chronological, nor is it always easy to ascribe to one person. In addition, current views of nature are not actually any more or less "scientific" than the now-discounted views of the past. Kuhn thus argues that "if these out-of-date beliefs are to be called myths, then myths can be produced by the same sorts of methods and held for the same sorts of reasons that now produce scientific knowledge."

As he moves through history, Kuhn emphasizes that many currently discredited theories were at one time considered to be highly scientific and precise. If that is the case, then the theories people today hold up as factual might be discredited by future generations and thought of as "out-of-date," similar to the way that many old beliefs are now thought of as fictional "myths." Kuhn thus blurs the line between objective science and creative myth.

As historians struggle with this problem, Kuhn suggests that "a historiographic revolution in the study of science" is already underway. Rather than studying scientists' work in relation to modern science, historians now study that work in the context of its own time. And rather than trying to invalidate past scientists, historians have started to try to understand them.

Though this book has some radical ideas, Kuhn was not alone in doing this kind of work. Many historians in the 1960s (when he was writing) were also trying to view intellectual history less through the lens of the present and more on its own terms. Kuhn's use of the word "revolution" is also interesting, as it links his project (a "historiographic" revolution) to the scientific revolutions that give the book its name.

Kuhn describes the "new image of science" that he and his fellow historians are trying to create. First, he wants to de-emphasize method as the main criterion of accuracy. Many scientists use legitimate methods, but their results differ because they have different expectations and beliefs. Kuhn then proposes that there is always something "arbitrary" in the expectations or areas of interest that inform scientific discovery. At the same time, that arbitrariness is necessary for scientists, as it allows them to ask focused questions about nature and to build on one another's work.

As he will continue to do throughout the treatise, Kuhn emphasizes that scientists are always guided by their particular beliefs about which facts are more important than others. These beliefs, grounded in scientists' particular education and life experience, are always somewhat "arbitrary"; the science that results from them, then, can never be fully objective.

The process by which these arbitrary assumptions are passed down through formal education is, in Kuhn's words, "normal science." Normal science "is predicated on the assumption that the scientific community knows what the world is like." It follows, then, that normal science does not encourage—and sometimes actively suppresses—new or divergent ways of thinking about the natural world.

Though scientists' beliefs may be arbitrary, they are also often shared by large groups. A major thread of Kuhn's argument is that science education, built on textbooks and problem-solving, teaches young scientists to adopt their elders' arbitrary beliefs. But while this textbook education allows for continuity, it leaves little room for invention or new thought. Instead, scientists tend to assume that they already "know what the world is like."

There are some moments, however, when trying to use normal science to solve a problem is impossible. In these moments, scientists question their received ("arbitrary") assumptions, and they focus their attention in new ways or go back to the drawing board entirely. This is what Kuhn terms "a scientific revolution." Scientific revolutions cause scientists (and often the broader population) to view and experience the world differently.

Sometimes, the beliefs or expectations handed down through textbooks blatantly clash with reality (and Kuhn will later provide ample historical evidence to back up this claim). To Kuhn, these clashes—"crises," as he calls them—are the most important, least studied element of scientific history.

There have been many scientific revolutions throughout history. Several of the most well-known revolutions are associated with scientists Nicolaus Copernicus, Isaac Newton, Antoine Lavoisier, and Albert Einstein. However, Kuhn believes that many less famous scientific revolutions are equally important.

Copernicus argued that Earth revolved around the sun, not the other way around. Newton introduced the idea of gravity and formulated crucial laws of physics. Lavoisier made important contributions to chemistry, particularly around the discovery of oxygen. Einstein is perhaps most famous for his theory of relativity, which linked space and time. Kuhn lists these well-known scientists together to emphasize his point that scientific progress isn't linear—instead, it's a constant cycle of revolutions, all of which are important.

Rather than a narrative of incremental progress, then, Kuhn sees scientific history as a cycle: scientific revolutions interrupt normal science, which leads to a new kind of normal science, which is then interrupted again, and so on. Kuhn acknowledges that history is often viewed more as a description than as a field that can cause "conceptual transformation." Yet he feels that his "circular" understanding of the history of science has "something important to tell us."

There are two crucial things to note here: first, if textbooks depict the history of science as a straight line, Kuhn sees it as a circle. Second, Kuhn again emphasizes that historians like himself have the ability to alter "something important" about how people understand the present.

CHAPTER 2. THE ROUTE TO NORMAL SCIENCE

Kuhn begins with a definition: "normal science" is the everyday practice of scientific research, an everyday practice that is usually on a single great discovery or idea. Normal science is popularized by the textbooks that hand down this knowledge to future generations.

Though normal science will eventually grow to include many specific beliefs and rules, Kuhn notes here that such science often begins with just one big, transformative idea about how the world works.

Kuhn then discusses the concept of "shared paradigms." These paradigms emerge with a very specific kind of discovery: first, the discovery must be brand-new and so compelling that multiple groups of scientists rally behind it. Second, the discovery must leave room for further exploration. Out of these initial discoveries spring whole bodies of scientific knowledge and research.

Kuhn's idea of a shared paradigm quickly gained popularity far beyond people who had read his book. But while the term is often taken to mean complete ideological unity, that is not accurate. Instead, Kuhn argues that scientists in a shared paradigm hold the same basic ideas about the universe, but they might try to fill in different gaps or focus on different areas within the paradigm.

A given scientific field cycles through a variety of these research paradigms; Kuhn gives the example of physics, which moved from a material view of light to a mathematical one. Crucially, however, there is also a time before paradigms for each science. In these pre-paradigm eras, many different scientists argued about what their fields' basic facts and focuses should be.

If a paradigm allows scientists to specialize and collaborate, pre-paradigm science is all about disagreement. Before a paradigm exists, scientists debate fundamentals; they cannot agree on what questions to ask or what methods to use.

In a pre-paradigm science, scholars cannot build on one another's work because there is no agreed-upon foundation. However, Kuhn emphasizes that it is important to understand that these early thinkers were equally scientific as their later counterparts. To demonstrate this argument, he cites the field of electricity before Benjamin Franklin.

Because of this disagreement, pre-paradigm science can never get very specific, because scientists are always trying to prove the basics to one another. Yet that does not mean that scientists in a pre-paradigm era are bad at their jobs. Kuhn is careful to note that even scientists who do not attract large followings might have precise techniques and brilliant ideas.

At the same time, there are major challenges to working without a paradigm. First of all, there is so much information available that without a single guiding principle or discovery, it is difficult to make all these facts make sense in the context of a particular scientific field.

Earlier, Kuhn has explained that "arbitrary" beliefs are always a part of science. Here, he clarifies why those beliefs are necessary—without them, scientists do not know where to start their research.

Paradigms then emerge to help scientists focus their attention on certain phenomena and questions. But while successful paradigms are usually more revealing than their competitors, they are never able to explain everything. Instead, they help scientists by allowing them new confidence and specificity. Or as Francis Bacon once put it, "truth emerges more readily from error than from confusion."

Paradigms provide clear starting points, and so they are immensely useful—but being useful is not the same thing as being accurate. And indeed, this Francis Bacon quote makes clear that what paradigms eliminate is "confusion," not "error." In other words, paradigms might bring clarity about how to proceed, but they do not necessarily bring truth.

When a new paradigm becomes popular, the older groups of scientists slowly disappear. Some of these scientists change their beliefs to match up with the paradigm. Others are simply ignored, and they must find new specialties or fields from which to develop their beliefs.

As more and more scientists devote their life to the new paradigm, dissenting views become increasingly frustrating and even threatening. Accordingly, scientists from different groups in the pre-paradigm era are pushed out of the field.

Similarly, as a paradigm develops, the scientists working in it grow increasingly specific in their discoveries. Therefore, scientific literature becomes less and less accessible to regular people. Only in pre-paradigm science does a scientific book have the same kind of audience that a book in any other field would have. Yet Kuhn argues that even if a paradigm makes discoveries narrower and less broadly useful, it is also the very thing that "proclaims a field a science."

Because scientists in a shared paradigm have a collective knowledge of the basics, all new discoveries are highly specific and based on prior knowledge. Normal scientific research is therefore inaccessible to anyone who lacks that prior knowledge (which is most people). However, this specialization is now viewed as an essential part of science because *it is so specialized.*

CHAPTER 3. THE NATURE OF NORMAL SCIENCE

Kuhn emphasizes that paradigms are often very limited when they emerge—they are successful not because they solve everything, but because they provide the tools that future scientists can use to tackle a variety of problems. Normal science is therefore a kind of "mopping-up" of the questions that the paradigm raises, in which scientists try to "force nature into the preformed and relatively inflexible box that the paradigm supplies."

Paradigms provide a set of questions and a place to focus, but they do not provide specific numbers of data points. The "mop-up" work that Kuhn refers to involves applying these big ideas to variety of specific problems. However, scientists in normal science are not looking to test the paradigm; instead, they are looking to affirm the "inflexible" view that the paradigm already supplies.

Again, Kuhn emphasizes that normal science actually discourages novelty and original thinking. But even as Kuhn criticizes normal science, he admits that it allows scientists to solve specific problems in a way that would be impossible without a guiding paradigm. There are three main kinds of knowledge that a paradigm allows its practitioners to focus on.

It is crucial to note that while Kuhn critiques textbook history, he does not critique normal science. Because it allows for specificity and quicker problem-solving, normal science is the foundation of most of the work scientists do.

First, scientists working on normal science must figure out new ways to observe the relevant facts in their paradigm (e.g., star positions in astronomy or wave lengths in physics). To do this, they will create new tools and apparatuses.

Here, Kuhn explains how normal science can actually bring about innovation. Although normal science can box scientists into a certain paradigm, this, in turn, encourages them to come up new tools or methods in order to work within that paradigm.

Second, scientists try and make nature line up with the paradigm theory's predictions. Once again, this involves investing in and inventing brand-new machines and technologies to measure various quantities.

The initial idea behind a paradigm usually involves a lot of predictions. One of the most important ways scientists justify their paradigm is by seeing that these predictions are borne out (even if they have to invent new tools or techniques to do so).

Third, scientists look for the actual numbers or rules ("empirical work") that make a paradigm theory applicable in the real world. Kuhn lists several examples of these kind of constants: there is Avogadro's number in chemistry, or Boyle's law in physics (both of which are named after the men who discovered them).

Paradigms begin with predictions and questions, not data. A big part of normal science is introducing these numbers or rules, which then form the basis of textbook problems—and so help educate the next generation of scientists in the paradigm.

A lot of scientific work in Kuhn's time involves scientists doing experiments to prove "points of contact between a theory and nature." This is generally considered to be an elementary form of science, as it merely involves carrying out trials to affirm what a paradigm has already predicted.

Some parts of the work in normal science are more obviously "mop-up" work than other parts. In particular, experiments to prove already-known data are usually done by younger scientists (for example, a high school lab experiment). The purpose of these experiments isn't to make a new discovery, but to observe an established theory play out in the real world.

Another major part of normal science is responding to the imperfections of the paradigm's first major discovery (what Kuhn calls "reformulating the paradigm"). For instance, when Newton's theories about planets' rotation neglected the gravitational force that planets exert on one another, many world-class mathematicians struggled to come up with a formula to explain this discrepancy. In the process, they discovered mathematical principles that improved many other fields of science and math. Kuhn thus argues that this kind of reformulation—which produces "a more precise paradigm"—is the most theoretical form of normal science.

Some elements of normal science at first seem to be about original discovery, though Kuhn argues that this is not really the case. The most advanced scientific work in normal science involves coming up with more concrete equations or applications that allow the paradigm's theory to match up more closely with observable reality.

CHAPTER 4. NORMAL SCIENCE AS PUZZLE-SOLVING

Kuhn reiterates that normal science is not interested in novelty—and in fact, discoveries that might upend the paradigm are often ignored or actively discounted. Kuhn then seeks to understand why scientists are so passionate about doing normal science. He argues that this kind of research allows scientists to "achiev[e] the anticipated in a new way"; in other words, normal science is about "puzzle-solving." Just as a **jigsaw puzzle** is a rewarding way of completing a pre-determined picture, Kuhn posits that normal science is an exciting method of proving what is already known.

Kuhn's jigsaw puzzle metaphor here is tremendously useful: each time someone begins a puzzle, they are trying to arrive at a predetermined solution—the picture on the box. However, no two people will solve the puzzle the same way; some might move faster than others, and everyone has a different strategy. In this sense, they're "achieving the anticipated in a new way." In the same way, normal scientists are arriving at familiar conclusions through their own novel, individual processes.

Importantly, many problems that people were trying to solve in the pre-paradigm era are dismissed once the paradigm comes into power. In this way, the paradigm further limits what kinds of questions and answers are acceptable (and thus tries to prevent itself from being invalidated or overturned). Kuhn thus believes that individual scientists are motivated less by a desire to be useful to the world and more by a desire to prove their problem-solving skills.

Paradigms focus scientists' attention on a set of data—and at the same time, they turn scientists' attention away from facts that might confuse or disrupt the paradigm. Paradigms are therefore self-perpetuating. It is also important to note Kuhn's focus on scientists' humanity here, as he turns attention to what motivates this kind of work. He suggests that scientists are driven more by a desire for people to admire their intelligence and skill than by altruism.

Continuing his **jigsaw puzzle** metaphor, Kuhn suggests that just as puzzles have rules (each piece must be turned face-up and interlocked with the others), so do paradigms. The most obvious kind of rule in a paradigm is the explicit laws associated with it: Newton's laws, for instance, or the laws of thermodynamics.

One of the main ways paradigms unite scientists is through these basic shared rules. (A famous example would be E = mc^2, Einstein's physics equation that describes the relationship between mass and energy.) These rules allow scientists to set up problems and find solutions in a way that is consistent throughout the discipline.

There are two other categories of rules: first, paradigms generally dictate what methods and technologies should be used to glean information. Second, there are "higher-level, quasi-metaphysical" beliefs that guide each paradigm. For example, Cartesian thinking (pioneered by René Descartes) told scientists that the entire world could be understood in terms of small molecular bodies interacting with one another. This belief gave scientists both a metaphysical understanding of the fabric of the universe and concrete way of solving problems.

Since scientists sharing a paradigm are looking for the same kind of information, it makes sense that they would use the same technologies and techniques. Importantly, though, scientists also share less tangible beliefs about the universe. Kuhn will later argue that because paradigms contain these "metaphysical" arguments about the world, scientists are affected not just professionally but personally when their paradigms are questioned.

Rules are important, but Kuhn does not think a paradigm is defined merely by its most important rules. Instead, he suggests that paradigms can still shape normal scientific work even in the absence of specific laws or methods.

Kuhn explains this more later, but he's hinting at what he will later label as the concept of "tacit knowledge": the idea that paradigms can be internalized and repeated through problem-solving, not just through explicit statements and laws.

CHAPTER 5. THE PRIORITY OF PARADIGMS

Speaking from his own experience, Kuhn reflects that as a historian, it is easier to isolate a paradigm than it is to articulate that paradigm's rules. This is because scientists can often "agree on their *identification* of a paradigm without agreeing on [...] a full *interpretation* or *rationalization* of it." In other words, scientists might share a set of core beliefs but disagree about the specific ways in which those beliefs are applied.

Even if scientists agree on the basics (what their shared paradigm is), they might squabble about the specifics (like why the paradigm is correct or what its principles mean in practice)—especially as normal science gets increasingly focused and precise. Kuhn therefore finds it easier to trace these big, paradigm-founding ideas through history than to trace the more specific rules of a given paradigm.

Rather than focusing on rules, then, Kuhn focuses on how a given paradigm can link a set of scientific problems. He draws on philosopher Ludwig Wittgenstein to explain the idea of "family resemblance": though there may not be one essential thing tying all the questions of a given paradigm to one another, the paradigm allows scientists to see the "resemblance" between their various questions.

Kuhn is often thought of as a philosopher as well as a historian, and this passage makes clear why that is the case: he applies the philosophical idea of "family resemblance" to the scientific idea of a paradigm. This concept of a family resemblance is useful in understanding the broadness of paradigms; scientists may be united around shared goals and values, but normal science allows room for many different kinds of day-to-day work.

Moreover, paradigms never exist purely in the abstract. Rather, scientists understand paradigms through their applications—for instance, young researchers learn about a concept like "mass" less from any one textbook definition and more from solving an equation that involves finding the mass of a given object. Thus, Kuhn argues, normal scientists work according to the rules of a game they might not conceptually understand.

Kuhn again gets at the idea of tacit knowledge (though he still does not call it by that name). Rather than reading about a paradigm, scientists learn to think through problems according to their paradigm's perceptions. But because they instinctively operate under the paradigm, they may not actually understand the basis of it.

Finally, Kuhn argues that rules are more important to normal science when paradigms are starting to collapse (just before and during scientific revolutions). But when paradigms are functioning well, no one tries to rationalize them—it is only when scientists begin to question the paradigm's accuracy as a whole that they also begin to question the paradigm's particular laws and methods.

Scientists are educated to trust their paradigm without question. It follows, then, that they only turn their attention to the rules when the paradigm has ceased to work seamlessly.

At the same time, Kuhn is careful to specify that contemporary science is not one unified study; there are many sub-fields and smaller paradigms within each larger discipline. Therefore, there can be smaller scientific revolutions, in which one group rethinks its paradigm while other larger groups continue with their practice of normal science. And fascinatingly, while rules tend to be more universal, paradigms—which draw on a shared history and set of intellectual commitments—are much more specific.

This is one of the more confusing pieces of Kuhn's argument. Yet in practice, it makes sense—everyone learns in high school class about basic laws like "objects in motion stay in motion." But more specialized, more expert groups of scientists know the values and minute observations that back those laws up. Therefore, paradigms are more specific and specialized than some of the crucial rules that they produce.

To exemplify this lack of unity, Kuhn shares an anecdote about a prominent physicist and a famous chemist. Both were asked whether a single atom of helium was a molecule. The physicist said no, and the chemist said yes, because each was drawing on their respective paradigms' different needs and expectations. Kuhn tells readers that in upcoming chapters, these kinds of "paradigm differences" will be tremendously important.

In this striking anecdote, Kuhn illustrates just how much a paradigm influences a scientist's view of the world. More importantly, though, this story demonstrates firsthand that disagreement within science does not mean that one field or belief (or one time period) is more valid or truthful than another.

CHAPTER 6. ANOMALY AND THE EMERGENCE OF SCIENTIFIC DISCOVERY

When people think of science, they are usually picturing normal science: it is cumulative, linear and very successful at finding answers. But how does normal science, which avoids novelty, end up producing scientific revolutions? In other words, Kuhn wants to investigate how discoveries "produced inadvertently by a game played under one set of rules" are able to illuminate another set of rules entirely.

Earlier, Kuhn articulated that scientific progress is cyclical (from normal science to crisis and then back again). Here, he argues that this cycle happens for a reason—crisis cannot happen without the traditionalism (and fear of novelty) inherent in normal science. It is only by operating under a certain "set of rules" that new ways of thinking can emerge.

Kuhn argues that a paradigm shift begins with an "anomaly": some case or instance in which the rules of the paradigm appear fundamentally at odds with nature. Scientists then explore that anomaly and create new basic assumptions with which to explain this unexpected fact. And finally, the paradigm shift ends when the "anomalous has become the expected."

Paradigms, with their rules and predictions, teach scientists what to expect. When something does not go according to expectation, then, normal scientists notice—and so anomalies are easier to spot the more established a paradigm is. Kuhn defines the process of a paradigm shift as noticing an anomaly and changing assumptions and rules to explain that anomaly. The paradigm shift is over when the anomaly becomes accepted rather than novel.

In turning their attention to the anomaly, scientists are also blurring the lines between factual and theoretical discovery. To illustrate this, Kuhn cites the history of oxygen science. In the 1770s, many different scientists were trying to understand oxygen; some were trying to isolate one gas from the other gases in the air, while others (like Lavoisier) were making sense of oxygen in terms of atoms and chemical energy. Real discovery, then, takes time, because it involves "recognizing both *that* something is and *what* it is."

In his exploration of the discovery of oxygen, Kuhn further complicates the simple, linear textbook narrative of science. Though scientists might notice an anomaly, it is not always clear whether that anomaly is an issue of theory or of fact. Making sense of an anomaly requires both noticing that the anomaly exists in the first place ("that something is"*) and uncovering what that anomaly means in the context of a paradigm (*"what it is*). No discovery is ever as straightforward (or as individualized) as textbook history makes it out to be.*

Lavoisier's discovery of oxygen initiated a paradigm shift. But Kuhn is careful to point out that Lavoisier had long been skeptical of the scientific knowledge he had been taught. Once Lavoisier started to notice an anomaly, his discovery of oxygen gave "shape and form" to the new paradigm that would allow him to depart from the received one. Many of Lavoisier's contemporaries, however, could never understand his work because they remained convinced of the old paradigm.

Again, Kuhn draws readers' attention to the human side of scientific progress. Though Lavoisier is heralded for his crucial contributions to chemistry, Kuhn is interested in the doubt and uncertainty (the personal and professional crisis) that spurred his work. Moreover, Kuhn makes it clear that while paradigm shifts can be dramatic, they often happen slowly over time.

The invention of X-ray machines also exemplifies this kind of discovery from anomalies. Wilhelm Roentgen, testing cathode rays, saw light glowing in an unexpected part of his apparatus. This surprise pushed him to develop the X-ray, which then opened entirely new doors in science. But again, other people had seen that strange glow before Roentgen did—and had ignored it, because it was incompatible with their accepted paradigm's beliefs.

If Roentgen wasn't highly educated and trained, he would not have known to be surprised by something as seemingly insignificant as a strange glow. Kuhn suggests that it's because Roentgen was so well-versed in normal scientific practice that he was able to notice even the slightest anomaly. This is how normal science makes crisis—and new discovery—possible.

The discovery of X-rays was not immediately greeted with applause; instead, many people were shocked and angered by such a radically new idea. Worse still, apparatuses that had been viewed in one way now had to be seen in another way, and so past scientific work was discounted and confused. Kuhn uses this example to argue that to use a given machine with a particular lens carries "an assumption that only certain types of circumstances will arise." These assumptions are necessary for normal science to proceed—and at the same time, the disruption of these assumptions is what allows for whole new ways of understanding the world.

Kuhn uses this X-ray anecdote to explore the idea that scientific technology, which is designed to meet the needs of a paradigm, must either transform in its usage or lose relevance as paradigms shift. In other words, even machines (which are, of course, neutral) are not purely objective and unbiased, because people use them under the "assumption that only certain types of circumstances will arise." In other words, scientific apparatuses can't be separated from human biases.

A final example of anomalous discovery is the Leyden jar (a major experiment in the field of electricity). Though efforts to create this jar were guided by the fluid theory of electricity popular in the 1700s, in the process of actually making the apparatus, scientists discovered the much more useful principle of electrical conduction.

Many scientists in the 17th and 18th centuries believed that electricity was an invisible fluid. As they tried to create a jar to capture this fluid, however, they realized instead that electricity is conducted (transferred) through certain substances like lead. This is an example of an anomalous discovery that led to a paradigm shift.

Kuhn then draws on a psychological experiment to argue that the longer someone pays attention to an anomaly, the more they are forced to acknowledge and make sense of it. In the experiment, people were shown some normal cards and some odd ones (like a black 4 of hearts). At first, participants assumed the anomalous cards were normal, but by the end of the experiment, they were rethinking the entire structure of a deck of cards.

Kuhn's multi-disciplinary interests again become evident here, as he turns his focus to psychology. In doing so, Kuhn also reminds readers that scientists, too, have personal psychologies—they share all humans' tendency to ignore the unexpected until the anomalous becomes so evident and undeniable that it reshapes expectations.

Finally, Kuhn argues that developed—specific—paradigms allow more easily for this kind of resistance. Only when scientists are looking for very miniscule, precise things (the very things dictated by the developed paradigm) can they notice that those things are behaving in unexpected ways. Therefore, the more rigid a scientific paradigm becomes, the easier it is for scientists to spot an anomaly. This is why scientific revolutions always come out of normal science.

As the X-ray story demonstrated, the rigidity of normal science is what allows for new ideas to emerge. This is one of Kuhn's central paradoxes: though normal science tries to prevent original thought, its strict boundaries are the very thing that ultimately cause the paradigm to collapse.

CHAPTER 7. CRISIS AND THE EMERGENCE OF SCIENTIFIC THEORIES

Kuhn points out that even as anomalies are constructive—leading to new discoveries and theories—they are also *destructive* of the knowledge that has come before. Moreover, just as anomalies are able to alert scientists to new kinds of phenomena, the scientific "crises" these anomalies cause usually lead to new theories. "Failure of existing rules," Kuhn explains, "is the prelude to a search for new ones."

Anomalies do lead to new ideas and discoveries. But, bolstering Kuhn's claim that science is far from linear, anomalies also destroy much of the research and experimentation that has been done in the last paradigm. Therefore, science is neither linear nor cumulative (as textbooks say it is).

To illustrate his point, Kuhn turns to astronomy. Ptolemy, an ancient Greek, had come up with a mostly reliable system for predicting the movements of planets and stars, in which he placed Earth at the center of the solar system. In fact, Ptolemy's view was so successful that some engineers still use it today. But as more and more people used Ptolemy's calculations, more and more discrepancies arose, and various scholars began to believe that "no system so cumbersome and inaccurate [...] could possibly be true of nature." This growing awareness prompted Copernicus to develop a model of the solar system with the sun at the center.

In Copernicus' time, the Catholic Church was focused on trying to create an accurate calendar to properly honor Christ's birth, death and resurrection. The Ptolemaic paradigm, though it had been accurate for centuries, was no longer sufficient. Copernicus' discovery—one of the most radical and important in the history of science—therefore came directly out of the crisis caused by the increasingly "cumbersome and inaccurate" calendar process.

As with Copernicus, Lavoisier's discovery of oxygen came out of a crisis—and as with Copernicus, many scientists thinking about oxygen in the 1770s struggled with competing applications of their supposedly shared paradigm. In fact, Kuhn sees the "proliferation of versions of a theory" as one of the key signs of a scientific crisis. And as Lavoisier and his contemporaries tried to adapt the existing theory (which centered on the idea of combustible "phlogistons"), their work began to look more and more like the competing works of a pre-paradigm discipline.

In Lavoisier's time, many people believed that there was a special substance called a "phlogiston" that was uniquely responsible for fire and combustion. However, different scientists applied this theory in such different ways that agreement became almost impossible—and so scientists could not collaborate or specialize as long as phlogiston theory persisted. Lavoisier's exploration of oxygen allowed the field to return to some kind of workable consensus.

Lastly, Kuhn cites an example from physics. As early as 1815, scientists were struggling to prove Isaac Newton's ideas that light is merely mechanical wave motion. But rather than paying attention to this anomaly, scientists ignored the experiments and tried to theorize new edits to the original paradigm. It was nearly a century before James Maxwell, a committed Newtonian, started to think about magnetism—thereby throwing Newton's theory into crisis and allowing Einstein, a few years later, to pioneer the theory of relativity.

Kuhn has previously mentioned that paradigms perpetuate themselves by ignoring all of the facts that do not support them. The century that elapsed before Maxwell was able to fully question Newton's ideas testifies to the strength of paradigms and normal science, which—if they are compelling enough—are able to preserve a scientific status quo for decades.

Kuhn notes several similarities between these three examples: one, it usually only took 20 or 30 years for a new paradigm to emerge out of crisis. Two, scientists recognized problems in the paradigm long before a full-on crisis emerged. And finally, other people or observations predicted the new paradigm but were ignored. In fact, the most famous foreshadowing of a discovery came from Aristarchus, an ancient Greek philosopher who argued (like Copernicus) that the sun was at the center of the universe—centuries before Copernicus was even born.

Several times throughout his book, Kuhn shows how science often repeats itself. No example is clearer than that of Aristarchus, who had the exact same vision of the universe as Copernicus did, only thousands of years earlier. Copernicus' rediscovery of Aristarchus' work (which he probably had not read) exemplifies this cyclical pattern.

CHAPTER 8. THE RESPONSE TO CRISIS

Though crisis causes scientists to abandon old paradigms, Kuhn believes that—at least according to the various historical examples he has studied—scientists never do so unless they have a new paradigm to replace the old one. To reject a paradigm without having another one is, Kuhn argues, "to reject science itself"; it would mean returning to a scattershot collection of opinions and beliefs.

Once scientists have some guiding theories and beliefs, they can no longer return to the confusing pre-paradigm era. In other words, once scientists have established some shared views, it is difficult to return to relying again only on their individual perceptions.

But while anomalies lead to crises, counterinstances (or moments in which the paradigm does not behave exactly as expected) are an everyday part of normal science. Kuhn thus posits that there is no clean line between what is an anomaly and what is merely another challenging puzzle for scientists to solve. And often, when scientists are unable to solve these puzzles, their colleagues see it not as the failure of the paradigm but as the failure of that individual scientist. Moreover, sometimes anomalies are resolved by discoveries in another field that offer a surprising solution.

Kuhn clarifies that not every anomaly rises to the level of crisis. Just as it took 100 years for James Maxwell to transform an anomaly in Newton's laws into a crisis, many anomalies are dismissed or resolved through new techniques and calculations. So, although some *anomalies cause paradigm shifts, not all do.*

Only very special kinds of anomalies, then, create crises. Sometimes this is because the anomaly has practical importance for society, as in the case of Copernicus (the Catholic Church was struggling to create an accurate calendar, and Copernicus was trying to figure out why). Sometimes, the anomaly grows more glaring as the field advances; sometimes, the anomaly cuts immediately and clearly to the heart of the paradigm. When a great many scientists have to pay attention to one anomaly, their responses to that anomaly start to conflict, and the paradigm begins to collapse.

Kuhn suggests that the closer an anomaly is to daily life, the harder it is to avoid or shrug off (as in the case of Copernicus and the calendar). And just as normal science makes anomalies easier to spot, paradigms help scientists come to consensus about which anomalies to pay attention to. Kuhn's focus on the nature of scientific communities, which becomes more prominent later in his book, is reflected in his attention to how scientists choose what really counts as an important anomaly.

Sometimes, scientists themselves recognize this breakdown: Einstein once said a moment of crisis in his field was "as if the ground had been pulled out from under one, with no firm foundation to be seen anywhere." But more often than not, crisis is not explicitly named. And indeed, normal science is often able to resolve crisis. In other cases, scientists give up, deciding they do not have the necessary equipment or knowledge to create a new paradigm. A complete scientific revolution, then, is relatively rare. But each crisis does "loosen" the rules and stereotypes of the paradigm it takes place in.

There are two important things to note in this passage. First, Kuhn explains that though not every anomaly leads to a crisis, each new surprise does chip away (even subtly) at scientists' belief in their paradigm. And secondly, Kuhn's use of this Albert Einstein quotation—in which Einstein is almost despairing—makes clear just how much an anomaly affects the personal lives of the people who are forced to reckon with it.

Moreover, as Kuhn insists, a true paradigm shift is not cumulative; instead, it requires scientists to go back to basics. To illustrate this point, Kuhn uses the idea of the Rorschach test (though he does not call it by this name). If in the old paradigm, scientists looked at a picture and saw a **bird**, now they have rotated the paper—and so they see an **antelope**.

This is one of the most useful examples Kuhn gives for understanding what a paradigm shift is: not just a change of rules, but a change of worldview and vantage point. However, Kuhn points out that while the bird/antelope drawing is reversible, paradigm shifts are permanent. Scientists cannot see the old world in the old way once they have seen it in a new light.

Kuhn then begins to describe the process of "extraordinary science." In contrast to normal science, which tries to reject or resolve the anomaly, extraordinary science works with the anomaly to create a new paradigm. However, Kuhn notes that it is more difficult to describe this process purely with historical fact; here, he admits that he is conjecturing more than he was in other parts of the book.

Extraordinary science is what the famous figures of science (like Isaac Newton or Galileo) practice; it's what creates new paradigms, and sometimes even new disciplines. In this passage, Kuhn also highlights his own personhood and subjectivity, admitting his lack of knowledge and thereby modeling such a process for the scientists he writes about.

The first step of extraordinary science, Kuhn argues, is to test out normal science by "push[ing] the rules" of a paradigm as far as they will go. The second step, as practiced by Copernicus and Einstein, is to isolate the anomaly and make it seem clearer and more out of place than it did initially—to "localize and define" what is actually differing from the paradigm's expectations.

Paradigm shifts are personally and professionally momentous, so anyone practicing extraordinary science needs to justify why such a shift must happen. In Copernicus's case, for example, that meant moving focus away from issues with the calendar and instead reevaluating the entire model of outer space.

Most importantly, Kuhn believes that extraordinary science often goes hand-in-hand with new philosophical thought (much of which comes out of the humanities). For example, Einstein's theory of relativity happened alongside a sea change in moral and social theory; it is not a coincidence, Kuhn writes, that "thought experiments" are a fundamental part of new paradigms.

If extraordinary science always involves deep-seated, metaphysical questions of belief, it makes sense that spiritual, religious and philosophical change would accompany paradigm change. Einstein's mathematical relativity thus went along with new theories in moral philosophy and with new movements in art focused on playing with viewers' perceptions.

Kuhn does not claim to understand how a person can eventually arrive at the beginnings of a new paradigm—how such an idea "emerges all at once, sometimes in the middle of the night." But he does note that such people are usually very young or very new to the field, and thus less indoctrinated into a given paradigm's rules and expectations.

This is an important passage for several reasons: first, Kuhn is again calling attention to scientists as humans. Second, he emphasizes that because scientific communities are so successful at teaching their doctrines, extraordinary science can usually only come from someone outside the field. And finally, Kuhn creates a temporal gap: normal science is routine and happens over a long time, whereas extraordinary science is dramatic and instantaneous—the latter emerges "all at once," like a sudden flash of inspiration.

CHAPTER 9. THE NATURE AND NECESSITY OF SCIENTIFIC REVOLUTIONS

Kuhn explains his choice of the word "revolution," which immediately suggests a parallel to politics. In fact, scientific revolutions are akin to political revolutions in that both see communities beginning to doubt or grow frustrated with established institutions. Moreover, in a political revolution, one set of institutions replaces another—but only after a temporary gap when society is not governed. The same could be said of the gaps between scientific paradigms, when science retreats to a pre-paradigm version of itself.

Because science is so often viewed as objective, consent and community are not often talked about in regard to scientific discovery. But here, Kuhn suggests that just as governments rely on the will of the people, scientific ideas can only exist when enough members of the field endorse them. When scientists abandon a paradigm, then, it is comparable to when citizens renounce their government—and it brings the same period of chaos that a political revolution would.

Most importantly, when a new political power assumes control, they must do so by persuading the populace. In science, the replacement paradigm will not be entirely correct, just as its predecessor had some holes. Rather, the new paradigm wins because it is the most persuasive: "there is no higher standard" for either a paradigm or a government "than the assent of the relevant community." It matters, then, that scientists are persuasive in the way they talk about their work and discoveries.

Kuhn's focus on persuasion here is noteworthy. If science were making a linear march toward the truth, persuasion would be irrelevant; each theory would naturally succeed and build on the last. But by focusing on the human and communal aspects of scientific progress, Kuhn also calls attention to the ways in which personality and chance—not objective truth—affect the history of science.

This persuasive element of scientific revolutions then helps explain why they are not cumulative. In order to have a convincing new theory, that theory must reject the aspects of the previous theory that contradict it—therefore making it almost impossible for one paradigm to build on another. However, very few people share Kuhn's belief that each paradigm is incompatible with the one that came before it.

Kuhn has argued that new theories emerge when old theories are broken, so it follows proponents of the new paradigm must work to destroy the old. Here, Kuhn draws a clear distinction between the popular, linear view of science and his own, which is circular and non-cumulative.

At the same time, old paradigms still offer important answers. This is true both of Newtonian physics, which is still widely respected, and of phlogiston chemistry, which is now mostly scoffed at. Kuhn argues that rather than linking these theories to the theories that replaced them, historians should acknowledge that the theories were successful in answering one specific set of questions—but collapsed in the face of another.

In the helium story, Kuhn showed that a physicist and a chemist could have very different—but equally valid—views of the same phenomenon. Here, he applies that concept across time. Some knowledge from old paradigms still has great use, as exemplified by the fact that scientists still rely on Newtonian physics (principles that are hundreds of years old) and even certain elements of paradigms that are considered outdated.

As an example, Kuhn explains that some people believe Newton's laws can be derived from Einstein's. However, Kuhn notes that Einstein has a different view of "the fundamental structural elements" of the universe. In other words, to derive Newton's law from Einstein's work, one must change the meaning of at least one of the men's works. Additionally, to even try to link the two is a luxury of hindsight and disregards what actually happened in the years between the theories.

For the first time in his treatise, Kuhn suggests that the linear history of science textbooks is not an accident but an active distortion. In order to legitimize the current scientific paradigm, science educators rewrite the history of science to make their own arbitrary work seem inevitable or objectively true.

Paradigms differ in the substantive ways they describe the universe. But each paradigm also entails a new set of methods, technologies, and problems—an acceptable solution in one paradigm is likely not acceptable in another. Kuhn then argues that paradigms are not only incompatible but incommensurable with one another.

"Incommensurability" is the idea that the very evidence that might prove a paradigm to its believers would seem completely irrelevant to people who disagree with the paradigm. Kuhn's focus on incommensurability thus points to the difficulty of even articulating a paradigm to someone outside of it, much less convincing them of its correctness.

To demonstrate the differences between paradigms (and to hint at the cyclical nature of science), Kuhn discusses the ancient Greek belief that physical objects had innate natures. This idea had been popularized by Aristotle, but by the 1700s, Descartes's idea of moving bodies (his "mechanico-corpuscular" view of nature) had taken its place. Many people viewed anything innate as "occult" and disreputable—until Newton published his *Principia*, which argued that gravity was an innate force. As the *Principia* became more widely used and respected, the ancient Greek view of innate properties came back into fashion.

Ancient Greeks believed that motion was innate, or built-in (as in, an object made of clay would fall quickly, because it came from the earth and so would return to the earth). Descartes mocked this theory, instead proclaiming that all motion was created by various particles in the universe bumping into one another (this is the "mechanico-corpuscular" theory). But because gravity (a relatively modern idea) is an innate force, existing in objects independent of their relationship to other objects, modern science is actually closer to Aristotle then to Descartes. This arc exemplifies Kuhn's circular view of science, because the way scientists think about the relationship between objects hasn't progressed in a perfectly linear way.

The idea of gravity as innate then had repercussions across other fields. In electricity, it helped scientists think through conduction as a built-in property. In chemistry, it allowed Lavoisier to build experiments based on the innate attractions of various chemical particles.

Just as Kuhn's own work reaches across disciplines, he notes the vast consequences of paradigm shifts across distinct fields of science. For instance, Newton's discovery in physics impacted Lavoisier's chemistry.

Importantly, Kuhn does not see any one paradigm as more legitimate than the others. For example, Cartesian scientists (those working in the paradigm established by Descartes) gave up looking for gravity because it did not make sense in the context of their guiding theory; ignoring gravity allowed them to make other valuable discoveries. And though Newton would make sense of gravity, centuries later, Einstein's work with relativity would return to something more like that of "Newton's predecessors than his successors." This once again demonstrates the circular nature of scientific revolutions.

If science is circular and not linear, as Kuhn claims, then a new paradigm is not any more impressive or accurate than an old one. Just as Newton's theory of gravity marked a return to an old idea, Einstein's theory of relativity resembled long-gone scientific ideas more than it did contemporary ones. Again, Kuhn's argument that each paradigm is both valid and flawed also chips away at the idea that there is one solid scientific truth.

However, this circularity poses a crucial problem. Each paradigm has its kinds of questions, with its own kind of acceptable solution, and each has different standards for what is valid and valuable. In a sense, then, each paradigm proves itself and so is self-contained. So, how can one paradigm ever triumph over the other? To answer this question, Kuhn suggests that in addition to being constitutive of science, paradigms "are constitutive of nature as well."

If each paradigm focuses only on the facts that support it, then it would seem impossible to ever disprove any one paradigm. In order to explain how paradigm shifts are eventually achieved, then, Kuhn turns his attention from paradigms as a thought experiment and instead focuses on paradigms as a lived experience for the scientists who work in them. This is what he means by paradigms being "constitutive of nature" as well as science—they reflect observable reality, not just abstract conjecture.

CHAPTER 10. REVOLUTIONS AS CHANGES OF WORLD VIEW

To some extent, Kuhn argues, "when paradigms change, the world changes with them." Though scientists are not literally transported to a new planet, they begin to understand the world in radically new ways. Again using the example of the Rorschach test, Kuhn suggests that each new scientific student's perception of the world "is determined jointly by the environment and the particular normal-scientific tradition that the student has been trained to pursue." When a paradigm shift occurs, therefore, part of the student's world changes.

Paradigms tell scientists both where to look and how to make sense of what they notice. So, just as turning a drawing of a bird sideways reveals a completely different picture (an antelope), thinking in terms of a new paradigm ushers in a new world. Kuhn thus emphasizes another facet of scientists' humanity here: their professional work impacts how they move through and experience daily life.

Using the field of gestalt psychology, Kuhn points out that once people have seen the world in a new light, it is almost impossible to revert to their old perceptions of it. However, bridging the gap between historical study and psychology presents an interesting problem for Kuhn's own work; he feels his work on this junction is not yet complete.

Gestalt psychology was a relatively new field in the 1960s, when Kuhn was writing. A "gestalt" is a whole that cannot be separated into component parts; gestalt psychology argues that people cannot perceive facts or details without taking into account context and prior belief.

In particular, while subjects of psychological experiments are able to acknowledge that the shift in reality is really a shift in their perceptions, scientists tend not to do so. Or, as Kuhn puts it, "looking at the moon, the convert to Copernicanism does not say 'I used to see a planet, but now I see a satellite.' […] Instead, a convert to the new astronomy would say 'I once took the moon to be […] a planet, but I was mistaken.'"

Once scientists start believing in a paradigm, they must reject what came before as false. After all, in order to feel any sort of certainty in any kind of worldview, scientists must blame themselves for error—not acknowledge that each conclusion is as arbitrary and subjective as the last. This is why Kuhn distinguishes between seeing two different things ("I used to see a planet, but now I see a satellite") and mistaking one thing for another ("I once took the moon to be a planet, but I was mistaken").

Kuhn also discusses the example of Uranus, a celestial body that was the subject of much debate among astronomers. Throughout the 1700s, many different people observed Uranus as a star, because they did not note its motion. When one scientist finally saw it move, he believed it to be a comet. After several months of unsuccessful efforts to assimilate Uranus into existing comet theory, scientists accepted that it was a planet. And suddenly, right after accepting Uranus as a minor planet, astronomers began to see minor planets and asteroids everywhere. Kuhn argues here that in changing their beliefs about Uranus, scientists looked up at the sky and noticed different things.

Here, Kuhn demonstrates that his claim that different paradigms make different worlds is anything but a metaphor. When scientists accepted that there could be minor planets, they dramatically changed how they looked at the sky—and so all of a sudden, the very same bright dots were named and treated in a whole new way. In simpler terms: once scientists believed the sky could filled with minor planets, all those minor planets suddenly appeared, and the sky itself changed for the scientists who studied it.

The most dramatic example of this shift in perception occurred with Galileo. Aristotle explained the pendulum by saying that heavy objects naturally fall, and the object at the bottom of the pendulum is merely falling slowly (because its chain holds it back). Galileo, however, began to take in the pendulum as a "swinging body" that repeats the same motion over and over again. This new way of seeing the pendulum allowed Galileo to come up with many critical scientific ideas about weight, incline, and velocity.

Later in the book, Kuhn will note that although Aristotle and Galileo understood a pendulum's movement differently, both were approaching it with detailed, methodical observation. The difference in Galileo's perspective—and the various rules it helped him create—was all about his internal beliefs, yet it led to a shift in how the world understood a wide range of external phenomena.

Kuhn notes that Galileo's "shift of vision" did occur in part because of "his individual genius." But at the same time, Galileo was drawing on the work of earlier scientists, who had come up with something called "impetus theory." His knowledge of impetus theory allowed Galileo to see the pendulum as something separate and specific, not just a "swinging stone." It was a knowledge of impetus theory, then, that allowed Galileo to see the world differently and therefore to conceptualize the pendulum.

Impetus theory, which was gaining popularity in the century before Galileo worked, dictated that once a force (an "impetus") sets an object in motion, the object continues in the direction of the force. Galileo's exposure to this theory, which had developed and spread slowly, allowed him to see the pendulum in a new light. This is another instance in which anomalies accumulate and reveal themselves slowly.

But if Galileo had gleaned insight from impetus theory, which was compatible with an old paradigm, Kuhn believes that his new way of seeing was ultimately the result of a "lightning flash" change in perception. In other words, if normal science leads to a crisis, it can never itself lead to a new paradigm. Instead, new paradigms are only reached by these almost intuitive reassessments of the natural world.

On the one hand, anomalies often emerge gradually; on the other hand, new paradigms—these breakages in scientific progress—emerge in an instant. More important, though, is the extremely unscientific way that Kuhn describes these changes in perception. This "lightning flash" moment is not objective and careful but personal and inspired, more like a moment of artistic genius than anything else.

Kuhn then pauses to consider why this focus on a given scientist's "immediate experience" is so necessary. For centuries, Western epistemology has argued that sensory experience is "fixed and neutral." Kuhn acknowledges that he does not believe sensory experience is really so simple—but that he does not have an alternative explanation. So, while Kuhn is confident that scientists' draw on their paradigm's assumptions for even seemingly factual observations, he lacks a theory of perception to describe *why* this is the case. Kuhn thus hopes for a paradigm shift in both psychology and philosophy that would help him explain this non-fixed, non-neutral form of perception.

Western epistemology, or the study of knowledge itself, has often assumed that observation is inherently unbiased: for centuries before Kuhn's writing, historians and philosophers of knowledge assumed that everyone took in their surroundings in the same way. In pointing out the flaws—or anomalies—in this epistemological paradigm, Kuhn's own work aims to resolve a crisis with a thought revolution in history, just as Copernicus, Newton and Einstein all did in their respective disciplines.

Stepping back, Kuhn notes that "neither scientists nor laymen learn to see the world piecemeal or item by item." For example, a child learning to call her mother "mama" is also learning about gender and family structures in general. Paradigms do not determine single facts or experiences, and so paradigm shifts affect many ideas and observations at once.

Kuhn is returning to the idea of the psychological gestalt, which states that people struggle to view individual objects or ideas removed from context—people see structures and systems rather than a "piecemeal" assortment of items. When one observation is altered by a paradigm shift, then, scientists will also have to shift their views of everything related to that observation.

Fascinatingly, then, science in a new paradigm involves many of same techniques, tools and terms as science in the old paradigm did. However, even when the same techniques and technologies are applied in a new paradigm, they are understood to reveal dramatically different information.

Earlier, Kuhn recounted how machines made to capture cathode rays later became X-ray machines. While the technology was the same, the use and meaning of such devices were completely different.

To exemplify this, Kuhn discusses the scientific revolution caused by John Dalton. For much of the 18th century, chemists worked under the paradigm of affinity theory, which dictated that certain substances dissolved in others because of an innate attraction. At the end of the century, some chemists began to realize that a select few chemical mixtures had fixed proportions of their various ingredients. But no coherent theory was created, and the discipline started to fracture (and appear more like pre-paradigm science).

Just as the Ptolemaic model became an impractical way of creating a calendar, affinity theory in chemistry was becoming more and more difficult to apply to everyday situations. In both cases, scientific communities began to fracture when faced with a reality that became harder and harder to fit into their paradigm's "box."

Dalton was ultimately the one who overturned affinity theory with his famous atomic theory. However, Dalton identified as a meteorologist—in his initial tests, he was not using affinity theory at all. Because he came from a different discipline, Dalton was able to craft the law of fixed proportion (all atoms will bond to one another in simple, whole-number ratios). At the same time, Dalton's theory allowed him to claim that any time ingredients in a compound were not in this kind of ratio, the compound was not chemical.

There are two important things to note about this passage: first, as a meteorologist, Dalton was able to view chemistry outside of affinity theory (and instead to think about atomic theory, which states that all molecules are actually made out of various smaller component parts). Second, as soon as he created a paradigm, Dalton immediately made it self-perpetuating.

Though some chemists were deeply opposed to Dalton's view, this new paradigm quickly proved more useful and efficient. Since even skilled scientists had been conducting their experiments with different goals and ideas (under a different paradigm), Dalton had very little evidence for his theory initially. Instead, that evidence came after—future scientists "beat nature into line," and when they were done, "the percentage composition of well-known compounds was different. The data themselves had changed."

The lack of evidence for Dalton's theory (at least at first) testifies to the ways in which paradigm shifts are more about creation than observation. But also, perhaps more than any other moment in the book, this anecdote illustrates Kuhn's point about the ways in which paradigms not only change science but change the very world that science is done in—a paradigm changes "the data themselves," in that scientists observe nature with the goal of fitting their observations into the paradigm.

CHAPTER 11. THE INVISIBILITY OF REVOLUTIONS

Kuhn turns his attention to the fact that the various scientific revolutions discussed in his book are rarely seen as such; instead, they are made "nearly invisible" to both laymen and scientists. This is in part because textbooks, popular science, and philosophy of science all focus on presenting the coherent laws and truths acknowledged by the "normal-scientific tradition" of the time.

Kuhn opened his argument with a critique of the simplified history in textbooks, and he now turns his attention to why (and how) this simplified history has developed. In particular, he is interested in how normal science bolsters its present activities by revising the story of science's past.

In particular, Kuhn notes that textbooks collapse after each scientific revolution and must be completely rewritten to reflect the new paradigm. Crucially, however, these new textbooks make no mention of this erasure. Instead, science textbooks "begin by truncating the scientist's sense of his discipline's history." Worse still, they replace this history with scattered references to old heroes that make students feel like they are taking in the history of their field—when they are actually learning about *only* the work that is most relevant to the current paradigm.

Throughout The Structure of Scientific Revolutions, *Kuhn has explained that scientists—more than experts in other fields—understand their purpose and practice through textbooks. One of the most powerful things textbooks can do, then, is to make young scientists feel like they are inheriting and improving an age-old set of scientific beliefs. In other words, science textbooks "truncate" the history of science in its full complexity and thus falsely assure scientists that their methods and questions are correct and inevitable.*

Though Kuhn acknowledges that all histories are to some extent revisionist, he believes this is especially true for science. On the one hand, science appears to be removed from historical context, and on the other hand, science is normally so authoritative on its own that it does not feel the need to justify itself with history. These textbook authors, Kuhn writes, wonder why they should "dignify" clashing beliefs—"what science's best and most persistent efforts have made it possible to discard."

While art and literature are usually viewed as products of a particular worldview or perspective, science claims universal authority, especially because many scientists' work has concrete impacts (like pain medicine or computer technology). But because science can solve problems, to acknowledge that science is subjective (and there might be another equally important set of problems) is to undermine the seeming clarity of scientific results.

As a result, textbooks often make science look linear. And in justifying their own paradigms, even some scientists themselves participate in this historical erasure. For example, Newton credits Galileo with discovering gravity in a Newtonian way, when in fact Galileo belonged to a different time and thought according to a totally different paradigm.

Kuhn's mention of Newton and Galileo demonstrates how important scientific certainty is even to the most radical thinkers. Rather than claiming credit for his new discoveries, Newton wanted to assure himself that he was merely continuing Galileo's legacy—and thus that his paradigm was inevitable instead of something he created.

In addition to erasing past scientific revolutions, this kind of history suggests that since the beginning of time, scientists have been trying to solve the same questions—the questions of whatever today's paradigm is. Many textbooks praise Robert Boyle as the first modern chemist because he defined the term "element" much as today's chemists do. But Boyle actually used this definition to argue that no such thing existed. Textbooks thus actively manipulate and distort the much more complicated, less linear, history of science.

Kuhn once again draws readers' attention to the importance of reading in context: a word that meant one thing in the 17th century might mean a totally different thing in the 19th. In other words, if textbooks work to read the past through the lens of the present, Kuhn insists that the history of science must be understood on its own terms.

CHAPTER 12. THE RESOLUTION OF REVOLUTIONS

Kuhn now turns his attention to scientists who have truly discovered something new (like Copernicus, Galileo, and Lavoisier). How did these men persuade their colleagues and ensure that their paradigms were the successful ones?

Kuhn's focus on persuasion is telling. He is not interested in how Lavoisier and Galileo arrived at more accurate paradigms, because he does not believe one idea is more truthful than another. Instead, he delves into the human element of scientific change.

In moments of crisis, scientists begin to test out the old paradigm to see if it holds up against various anomalies. At the same time, they begin to compare this old paradigm to the new theory (or theories) that are threatening to replace it. But again, these tests do not lead to one perfect, completely accurate theory. Instead, as Kuhn writes, "verification is like natural selection: it picks out the most viable among the actual alternatives," even though more useful ideas may just have yet to be thought up. In other words, the winning theory is not the best theory; it is just the theory most able to persist.

Here, Kuhn compares paradigm shifts to Charles Darwin's theory of evolution through natural selection (a comparison he will repeat at the end of the book). This comparison suggests that new scientific theories emerge not in spite of *context but* because of *it—at a given moment, a given idea might be best adapted to solve problems and convince other scientists of its validity.*

Historian Karl Popper believes that it is falsification of theories—and not verification—that determines which paradigm will flourish. Kuhn sees Popper's idea of falsification as another way of talking about anomalies (and the crises that come from them). In that case, Kuhn imagines a "two-stage formulation" in which theories compete both by verifying themselves and by falsifying their competitors.

In the theory of natural selection, some species triumph over others because they are able to hoard or steal resources from their fellows creatures. In the same way, new scientific theories succeed not only because they are successful but because they point out their competitors' failures.

Paradigm verification is never so simple, however. Each worldview has such different basic assumptions that often, paradigms are "bound partly to talk through each other," failing "to make complete contact." Moreover, each paradigm tries to "banish" questions that the other ones hold dear. For example, Newton claimed it was unimportant to understand why certain attractive forces existed; Einstein's relativity tried, above all else, to solve exactly the problem that Newton ignored.

Earlier, Kuhn has argued that if different paradigms entail different experiences of the world, scientists working in different paradigms are also working in separate universes. In this way, they fail "to make complete contact" with one another; Kuhn refers to this conflict as the "incommensurability" of different paradigms. This clash then makes it difficult for scientists to persuade people whose very lived experience is at odds with their own.

Moreover, because each new competing theory borrows—and alters—some concepts and techniques from the old theory, proponents of different theories are using the same language to talk about contrasting ideas. There is always "misunderstanding," then, between the competing paradigms, and Kuhn is firm that "communication across the revolutionary divide is inevitably partial."

In his discussion of textbooks, Kuhn emphasizes that many paradigms use the same word to signify different ideas. Here, he demonstrates just how unreliable and "partial" language is. This linguistic failure also helps illustrate why tacit knowledge is such an important bonding force for scientific communities.

Most importantly, it is difficult to compare paradigms because of something Kuhn struggles to define. "In a sense that I am unable to explicate further," he explains, "the proponents of competing paradigms practice their trades in different worlds." Some of the concepts in each paradigm are believed or intuited and so cannot always be proved by logic. "Like the gestalt switch," in which a **bird** suddenly appears as an **antelope**, "it must occur all at once, or not at all."

There are several important things to note in this passage: first, Kuhn again emphasizes that paradigm shifts are instinctual and almost illogical. Second, Kuhn again asserts that the gap between scientists in paradigms is not just theoretical but experiential. And most fascinatingly, Kuhn expresses his own intuition here—in confessing that he is "unable to explicate further," Kuhn shows his own humanity to his readers (just as he often points out scientists' humanity).

Indeed, most new paradigms do not take hold while their creators are still alive. Charles Darwin (who first conceptualized evolution) and Max Planck (who pioneered quantum physics) acknowledged as much in their treatises. Planck even wrote that "a new scientific truth does not triumph by convincing its opponents […] but rather because its opponents eventually die."

Just as many paradigm shifts are initiated by people who are very young or new to their field, established scientists have the most trouble with such a radical change in their beliefs. For many such people, a true shift in mindset is impossible; Kuhn believes it is more likely that these people will die than that they will be persuaded.

But rather than seeing this miscommunication as evidence of scientists' stubbornness, Kuhn believes that a paradigm shift is "a conversion experience that cannot be forced." If normal science is effective because it gives scientists confidence in their beliefs, then uprooting those beliefs in a paradigm shift is necessarily difficult.

Kuhn has repeatedly highlighted scientists' emotions and biases as important aspects of their worldviews—and, consequently, their work. But in using the word "conversion," he blurs the line between objective science and internal spirituality (paralleling his earlier comparison of science to "myth").

It is impossible to generalize about why some scientists are eventually persuaded. But Kuhn is careful to note that "conversions occur not despite the fact that scientists are human but because they are." The most effective claim, however, seems to be that the new paradigm can solve the problems that caused the old one to collapse (e.g., Newton could use his theory to make much more accurate quantitative predictions about stars and planets).

Surprisingly, rather than critiquing scientists' belief systems, Kuhn suggests that this kind of personal perspective is an essential ingredient of new discovery. So, while Kuhn pushes back against the narrative that science is objective, he also celebrates scientists' subjectivity.

However, this claim to effectiveness is not enough by itself. And in fact, it is not always true—Copernicus's measurements of the heavens were not any more accurate or useful than Ptolemy's. In these cases, theories often gain converts many years after they are thought up, when an unexpected phenomenon seems to affirm them. For example, Copernicus had been dead for 60 years when a new kind of telescope proved many of his hypotheses. Einstein was luckier: in his own lifetime, his theory was born out by the planet Mercury's motion.

As Kuhn demonstrated in the case of John Dalton's atomic theory, many paradigms initially begin more with predictions than with evidence. When reality conforms to a theory's prediction, it is only natural that such a theory becomes newly awe-inspiring, gaining converts who might have scoffed initially.

Finally, some paradigms succeed because they are almost aesthetically pleasing in their neatness. This is especially important because accepting a new paradigm often requires a leap of faith; usually, the theory does not yet have the evidence to back it up. Aesthetic considerations—when the paradigm is simple to use or easy to understand—therefore help people take this leap of faith.

Aesthetics are a crucial part of art and literature, but rarely is science discussed in aesthetic terms. By arguing that the style and simplicity of a given theory matters, Kuhn once again shows how scientific change is driven more by a community's preferences and less by a single, objective truth.

If an individual's initial conception of the paradigm is a "lightning flash," the persuasion stage is much slower. Not all scientists are persuaded at once. Instead, members of the profession gradually shift, and as support for the paradigm grows, additional scientists are less cautious about joining in. Yet Kuhn maintains that while it might be *unreasonable* for scientists to resist new paradigms forever, it is never *illogical* for them to do so.

Again, Kuhn focuses on the group mentality that allows scientists to collaborate with one another; it is easier for scientists to adopt new ideas as a group than as individuals. Equally important, however, is the fact that this shift is about social and intuitive knowledge, not about logic—in fact, Kuhn implies that it is almost more logical for scientists to resist new paradigms than it is for them to convert.

CHAPTER 13. PROGRESS THROUGH REVOLUTIONS

Finally, Kuhn turns to the question of progress. Why is science believed to progress in a way no other field does? Art, for example, is not viewed in a linear way. Kuhn also flips the question, suggesting that science is defined by progress: "to a very great extent the term 'science' is reserved for fields that do progress in obvious ways." Kuhn then questions why science is so separated from other kinds of work.

For much of his treatise, Kuhn has argued that scientific progress moves in a circle, not a line. But here, he complicates that argument—because he suggests that for many, linear progress is not only a feature of science but the very thing that defines it. In other words, many people seem to believe that if a field moves in a straight line toward truth—rather than sewing doubt or introspection, as art would—that field is automatically a science.

First, Kuhn reflects on the figure of Leonardo DaVinci, who could go back and forth between science and art. Even after DaVinci's time, the term "art" applied just as much to technology as it did to painting. But now science is siloed off, defined by progress and objectivity that is not necessary in other fields.

In the modern world, creativity is reserved for artists, while objectivity is reserved for scientists. But Kuhn hopes to return to the DaVinci model, in which science is as much about "aesthetics" as it is about facts.

Kuhn next reflects on the fact that artists and people in the humanities do make a kind of progress. But rather than trying to view such progress as linear, non-scientists merely try to add new ideas and creations; often, these ideas are in conflict with one another, but no one in these fields views that as disqualifying or negative. This disagreement is not possible in normal science because it is guided by a single coherent paradigm.

Whereas disagreement is a sign of crisis or collapse in the sciences, disagreement is considered to be a vital and exciting part of the arts. As Kuhn will discuss more explicitly later on, these differing views of disagreement point to the fundamental structural differences between artistic communities and scientific ones.

Interestingly, Kuhn also notes that scientists—more than any other professionals—only address their work to one another, while most artists or theologians want their work to reach a broad population. And indeed, because scientists are speaking to a smaller audience, they have fewer contrasting viewpoints to contend with. Plus, because scientists are not necessarily trying to appeal to the public, they can choose areas of focus not because they are societally urgent but because they are probably *solvable*. Since scientists pick problems specifically to solve them, it follows that science often progresses faster than other fields (like theology or medical care).

Great art often asks its readers of viewers to question their received knowledge or beliefs. Great science, on the other hand, affirms a pre-existing set of ideas by applying these ideas successfully to a new problem. Kuhn's realization that scientists pick "solvable" problems again demonstrates how paradigms perpetuate themselves: because paradigms are formed to answer specific questions, focusing on those questions will likely lead to results that support the paradigm.

Kuhn also draws his readers' attention to the way scientific education differs from other types of education. In most fields, students read a variety of primary works, many of which express different viewpoints, beliefs, or styles from one another. In science, however, textbooks are "systematically substituted for the creative scientific literature that made them possible"—and as Kuhn has already discussed, textbooks present a particularly linear, simplified view of the history of science.

As Kuhn has noted many times, scientific paradigms begin with individual, personal flashes of insight—just like paintings or plays tend to. In addition to erasing any conflict between these insights, then, textbooks also erase the fact that such revelations are often spiritual and subjective in nature.

Rather than condemning this education, however, Kuhn notes that it prepares students for normal science. And because normal science is what allows for moments of crisis (and subsequent scientific revolutions), this textbook-based education also helps to make paradigm shifts possible. However, it does not necessarily equip students to think outside the box in the way that is necessary once a new paradigm has replaced an old one.

Kuhn, reiterating an earlier point, acknowledges that the specificity of textbooks allows scientists to notice anomalies in a way they would not be able to otherwise. At the same time, textbooks—in their simplified content and their emphasis on tacit knowledge—make it difficult to confront the crisis such an anomaly might create.

Finally, Kuhn argues that science and progress are associated precisely because there are so many scientific revolutions. When one group emerges victorious from a moment of crisis, they are determined to announce that victory—and thus to rewrite the history of science in their favor.

This is a crucial insight: to ensure that their paradigm is successful, scientists must paint this new idea as a marker of progress. In other words, the popular belief that scientific progress is linear is an idea that scientists themselves help to spread.

But Kuhn does not believe that in science, "might makes right." Instead, he tries to articulate the specific characteristics of scientific communities, which function based on mutual agreement and shared beliefs. In particular, Kuhn believes that most scientific progress was made in Europe from 1600 on; he therefore focuses mostly on a modern Western view of the scientific community.

Kuhn is careful to note that a paradigm cannot gain force on revisionist history alone. And while Kuhn pushes back against some classic Western ideas about knowledge, he has also written this entire book with a Euro-centric lens—he isn't unbiased either.

Kuhn lays out the criteria of such communities: first, the scientists must be concerned with problems of nature. Second, they must work in some detail and with some degree of focus. Third, scientists must accept solutions not as individuals but as a group. Fourth, scientists must have some sort of credentials and education (be members of "a uniquely competent professional group"). All these characteristics set groups of scientists apart from other groups of professionals.

Though all of these criteria are important, perhaps the most fascinating element of scientific communities is the fact that such a community must always accept or reject ideas as one. Kuhn began his book by suggesting that agreement was what made one idea emerge as science while another was dismissed as speculation; here, Kuhn begins to study how such agreements are actually reached.

Since scientific groups have a shared knowledge of which problems have yet to be solved, paradigms are selected not because they are new but because they offer "concrete problem-solving ability." Similarly, new paradigms often narrow science rather than broadening it; they allow for depth, not breadth.

Because paradigms allow scientists to collaborate with one another, each individual is able to focus on one very specific element of the larger paradigm. Working in community therefore allows for individual scientists to feel more successful day-to-day than they would if they were working alone.

Kuhn has consistently argued that "scientific progress is not what we had taken it to be." But now, he goes further, arguing that society has to "relinquish the notion, explicit or implicit, that changes of paradigm carry scientists and those who learn from them closer and closer to truth."

This is arguably the most radical claim in the entire book. Here, Kuhn reveals that in casting doubt on the idea that science is linear, he is also questioning the belief that science will ever arrive at a set destination—namely, objective truth.

Kuhn then points out that he has not used the word "truth" at all in his book (except in a quote from Francis Bacon). Science is so often the field in which objective truth seems most possible, but Kuhn argues that no such thing exists. Instead, he advocates for valuing science not because it explains a universal truth but because it answers a certain set of particularly relevant or interesting questions.

While scientists may find new solutions to new kinds of problems, Kuhn doesn't believe they have any more access to the truth than a painter or a poet does. In a way, then, Kuhn is calling for society to value science in the same way that people value artwork: because it is interesting and valuable, adding a new perspective without ever providing certainty.

To articulate the difficulty of his proposal, Kuhn turns to Darwin. When Darwin proposed evolution, what upset his contemporaries was not the process of gradual change that he described. Instead, fellow scientists were horrified that there was no end goal; in Darwin's mind, living beings were not heading toward some form of perfection. Instead, they were merely changing to adapt to whatever environments and circumstances they found themselves in.

Kuhn now follows up on his earlier comparison between scientific progress and natural selection. In particular, he emphasizes that just as evolution rewards creatures that can best adapt to their environment, science rewards thinkers who can answer the most pressing questions of the historical context they're living in.

Kuhn has argued for something similar in science: rather than progressing toward a single goal, new ideas and paradigms have adapted and succeeded through a kind of natural selection. There is a larger question here that Kuhn does not claim to know the answer to: "what must the world be like in order that man may know it?" Instead, he only claims to have presented a new lens through which to observe science—a lens that, in many respects, mimics nature itself.

In the final paragraph of his original publication, Kuhn suggests that science will never reach a plane of perfect knowledge. Kuhn does not even know how such knowledge could be possible—but he believes that the world itself would have to become more knowable, as such understanding could never come from people. But rather than lamenting this circular, never-ending history of science, Kuhn suggests that it is worth appreciating in the same way people appreciate nature, even in all of its mystery.

POSTSCRIPT - 1969

Almost seven years after the initial publication of *The Structure of Scientific Revolutions*, Kuhn returns to clarify some of his ideas. Partly, he is responding to readers' criticisms or misunderstandings. Partly, he is hoping to incorporate his own later knowledge and research.

Again, Kuhn's willingness to question himself reveals him not just as the book's writer but as a human being; like the scientists he studies, Kuhn too has specific biases, beliefs and an ability to change his mind.

First, Kuhn reiterates that paradigms are circular—and therefore he wishes that before leaping into this circular narrative, he had begun his original text with a discussion of "the community structure of science." More than in other professions, Kuhn believes that scientists belong to communities: the members of a community have had very similar educations, and they have very specific sets of shared goals. Within these groups, there may be many sub-groups (and in fact, each sub-group may only have a few hundred members).

Kuhn seems to shift the focus of his original work: his initial over-arching claim was that scientific history moved in a circle, not a straight line. But now, he seems to suggest that such a claim is itself an offshoot of the particular nature of scientific communities; looking back, he feels that his most important contribution to history is his focus on these communities' structures and quirks.

Kuhn also specifies that even in pre-paradigm periods, scientific communities share some basic ideas and beliefs. What really changes in a paradigm shift is that the shared beliefs become more specific—they offer more "challenging puzzles" and supply better "clues to their solution."

Here, Kuhn is narrowing and clarifying his initial claim that scientists begin from total disagreement with one another. Instead, he argues that even subtle disagreements can pose huge hurdles to collaboration and specialization.

Finally, Kuhn responds to the criticism that he only cares about major scientific revolutions (ones that affect large groups of people). On the contrary, Kuhn believes that the smaller, everyday scientific revolutions—which may affect as few as 25 people—are the most important, as it is these revolutions which most demonstrate the need for Kuhn's argument. Similarly, he acknowledges that the crises that start paradigm shifts may be introduced from other disciplines or subgroups.

Major paradigm shifts (like those sparked by Copernicus and Lavoisier) are highly uncommon. Naturally, then, Kuhn does not want his argument to apply merely to these few rare instances. Instead, he wants to reshape the more frequent, smaller-scale paradigm shifts that might affect even tiny, highly specialized groups of scientists. By applying his theory to these smaller communities, Kuhn perhaps hopes to change scientists' view of their own daily practice.

In the next section, Kuhn revises his blanket use of the term paradigm, which he feels he originally used in two contradictory ways. Rather than saying that scientists all share a single paradigm, he coins the new term "disciplinary matrix" to describe the shared set of theories, rules and beliefs that guide a given discipline at a given moment.

Frequently, Kuhn describes the important of precise language (and the difficulty of creating a shared language). His emphasis on the exact terms used in his book reflects his understanding that language is often trickier and less clear than it seems.

One important part of any disciplinary matrix is the "symbolic generalizations" shared by a group of scientists (whether that is a set of rules or a set of definitions). But there is also a deeper aspect to these disciplinary matrices—these frameworks, Kuhn notes, "supply the group with preferred […] analogies and metaphors." And finally, Kuhn notes that shared disciplinary matrices dictate a set of shared values, whether that is an emphasis on prediction or on accuracy or on plausibility. However, values may also differ (to some extent) between individuals in the group.

As Kuhn himself points out, the word "paradigm" appears in his book with various meanings, some specific and some vague. In creating this new term, Kuhn is also able to specify what, exactly, scientists are able to share with one another—namely, specific rules, linguistic entry points, and deep-seated values.

Kuhn also redefines the crucial problems of a given paradigm as "exemplars." These exemplars (usually famous experiments that helped to clarify the overarching disciplinary matrix) help students learn about a field, and they are also the main source of symbolic generalizations.

Though the original version of The Structure of Scientific Revolutions *did emphasize just how important problem-solving was to scientific education, Kuhn now begins to look more precisely at how such "exemplars" actually shape young scientists' viewpoints.*

In the next section, Kuhn argues that exemplars deserve special attention because "the paradigm as shared example is the central element of what I now take to be the most novel and least understood aspect of this book." Kuhn argues that when a student tries out several textbook problems using certain rules and assumptions, they begin to assimilate a "time-tested and group-licensed way of seeing." In other words, they begin to view the world according to their discipline's framework.

More than any concrete laws or metaphysical beliefs, Kuhn asserts that the example-based, tacit knowledge taught in textbooks is the fundamental thing that unites scientific communities. Again, the bird-antelope Rorschach test analogy is useful here: when science students do textbook problems, they learn (metaphorically) what angle to hold the paper at in order to see the same drawing—or world—that the rest of their colleagues do.

To exemplify this, Kuhn references the phrase "actual descent equals potential ascent"—this is a law built on Galileo's experiments rolling a ball down an incline. These words mean nothing to a student who has not had some sort of exposure to "the ingredients of nature" as Galileo understood them. But after the student does several problems involving motion, weight, and inclined planes, they can begin to understand these words as other scientists mean them. There is thus a kind of "tacit knowledge" involved in paradigms, "which is learned by doing science" (trying out textbook-like problems) "rather than acquiring rules for it."

For the first time, Kuhn himself introduces the term "tacit knowledge" (though it is useful to apply such a term to earlier parts of the book). This kind of knowledge, based on problem-solving, allows students to internalize some of core beliefs and perspectives of a given paradigm/matrix. But at the same time, because such knowledge is experiential and largely unspoken, many students understand how to apply a paradigm better than they understand how or why that paradigm came to be accepted.

Next, Kuhn clarifies his claims about intuition. Rather than referencing intuition as a mystical force, he explains that he is talking about the different ways that people can feel and perceive almost identical stimuli. Because people's own personal worlds are determined not by stimuli but by the "sensations" they feel in response to those stimuli, everyone does to some extent live in a different world from everyone else. Kuhn then argues that one of the fundamental principles of a paradigm is that it allows various members of a scientific group to feel the same sensations in response to the same stimuli. More than just a shared set of rules, then, this kind of shared seeing—like the shared "tacit knowledge" Kuhn has just discussed—defines a paradigm.

Though Kuhn certainly does see a spiritual element to the "conversion experience" of paradigm shifts, he clarifies here that he is focusing not on any kind of magic but on scientists' lived experiences. In other words, Kuhn reminds his readers that scientists are, first and foremost, human beings. Moreover, he suggests that the great triumph of science is that it allows scientists to share what would otherwise be purely interior, individual sensations with a whole group of people.

Kuhn thus calls attention to the neural apparatus that governs perception. In particular, he argues that just as certain ways of perceiving allow humans being to survive from one generation to the next, certain responses to stimuli are more effective than others—and are thus easier for one generation of scientists to hand down to the next.

Now thinking through the lens of stimuli and sensations, Kuhn offers another explanation for why some paradigms take effect over others. Maybe, he seems to imply, successful paradigms just line up more closely with scientists' lived experiences than their competitors do.

Speaking mostly to the philosophers of science who criticized his original text, Kuhn clarifies his remarks about the incommensurability of paradigms. Rather than saying that believers of different paradigms can never understand each other, Kuhn specifies that "translation" of different words and concepts gives scientists operating under different paradigms some small ways of understanding one another.

Persuasion across paradigms does happen; otherwise, scientists would never leave the pre-paradigm phase of their work. By introducing the concept of translation, Kuhn clarifies his earlier argument by suggesting that cross-paradigm communication, while possible, always involves an extra step.

Translation across paradigms is therefore one of the crucial tools of persuasion. However, Kuhn is realistic about the fact that translation is often difficult and complex—especially because it is so foreign to the practice of normal science. He also acknowledges the principle (which he draws from linguistics) that understanding a theory in translation is very different from actually experiencing that theory in its original form. All translation may really do, then, is provide "points of entry" to an otherwise-strange paradigm.

At the same time, though this kind of translation gives scientists some access to each other's perspectives, it cannot substitute for the deeply felt, intuitive change that always accompanies a personal shift in a scientists' beliefs.

In the penultimate section, Kuhn responds to criticism that he has taken a relativist view of science. To make his case, he argues that one could make a sort of evolutionary tree of all modern scientific specialties. One could then easily formulate a list of criteria—"accuracy of prediction," "simplicity, scope, and compatibility with other specialties"—that would show how the more recent theories have advanced beyond the first ones.

Kuhn is essentially claiming that progress and improvement are different things. Over time, science has been improved in many ways: many disciplines are now far more precise, more specific, and more aesthetically pleasing than they were in Aristotle's time. In other words, scientists can develop new and more advanced techniques in much the same way that novelists grow increasingly experimental with their form, style, and technique.

At the same time, while later scientific theories may be simpler or more accurate predictors than their predecessors, Kuhn reiterates his belief that science is still not getting any closer to an objective truth—to what is "really there."

Kuhn's belief about science is similar to the idea that a more structurally complex novel (or a piece of multimedia artwork) is not any more revelatory than a simple story or painting. So, while science may appear neater or more precise than art, Kuhn argues that it does not arrive at what is "really" the truth any more than new art does—because reaching objective truth is impossible.

In his final section, Kuhn responds to two dominant views of his original book. Critics believe Kuhn is switching back and forth between description (how things are) and prescription (how things should be). Kuhn feels that this is a less clear distinction than many would like to pretend. Indeed, he believes that his argument both describes how scientists *do act* and suggests how they *should act* in the future.

At the very beginning of his book, Kuhn argued that history could have concrete effects. Now, he reiterates and clarifies that argument; when scientists understand the subjectivity of their work, he suggests, they should feel new freedom and be able to more effectively communicate with one another.

Kuhn also is uncomfortable with the many readers who applaud his work because it can be applied to other fields. On the one hand, his work does apply the revolutionary structure of politics or art to science; as Kuhn puts it, "revolutionary breaks in style, taste and institutional structure" are a central part of art history and political history alike.

Kuhn feels that those who apply his theory to other disciplines are reversing his true argument. Indeed, Kuhn frequently points out that revolutions are everywhere; he has simply been trying to apply a pattern that has long been acknowledged in art and politics to science.

But on the other hand, Kuhn reiterates that he is most interested in the way that science is *different* from other fields. There is less room for competing conclusions in science, and scientists speak to a much narrower audience. Most of all, science prioritizes **puzzle-solving** over creation in a way no other field seems to do.

But while art and politics are defined by disagreement and individuality, science has long been defined by agreement. It is this community consensus that sets science apart, and it is this consensus that Kuhn feels—especially in the postscript—is the central focus of his book.

To close his book, Kuhn calls for more study of intellectual communities as a whole (both scientific and non-scientific). After all, scientific knowledge only exists if it is shared by a group—and so understanding these groups is key to understanding scientific knowledge.

In many ways, Kuhn himself has created a new paradigm. He has identified a crisis in the history of science, and he has shifted his perspective to see cyclical progress and intuition where once people saw linear success and objective fact. In his final paragraph, then, Kuhn calls on others to study more deeply the kind of communication and collaboration he writes about—inviting others to do the "mop-up work" that will turn his great idea into a workable paradigm.

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