CHAPTER 1

Paradigm Shifts, Incrementalism, or Both?

What are the major attributes of life? The nature of the problem: Is it sudden Kuhnian paradigm shifts or is it an incremental change over time similar to the evolutionary process in which the past is modified with new knowledge and new techniques modifying a basic concept that is retained? Are both processes involved? What to look for to sort out the three possibilities.

Science as we know it begins in the 16th century with the work of Galileo Galilei and Renaissance scholars in Europe, especially in Italy, Great Britain, and Central Europe. Today we identify science with the union of technology, rational thinking, interpretation of data, a rejection of the supernatural as an explanation of observable phenomena, and experimentation to test or modify the implications of theories and inferences. Those components may have existed in isolated instances throughout human existence, but the Renaissance saw the first systematic effort to apply all of these to the physical and life sciences. If we contrast this modern science outlook that still prevails today with the knowledge of science in ancient times, we would see profound differences in how the world was seen. To those ancestors, the motion of the planets and the positions of the fixed stars were a source of information about oncoming misfortunes, good times, royal births, or sudden catastrophes. Astrology, not astronomy, was primary when studying the skies in an era that would not have telescopes for another two or three millennia. Mathematics was relatively secure as an exact science because of the rational nature of mathematical proofs. But even the Greeks, especially the Pythagoreans, saw in the patterns of numbers some connection, spurious as well as valid, to astrology and the arts (e.g., musical scales) and a possible divine aspect to their shapes or patterns. That belief in numerology later fed religious traditions (e.g., Kabbalah, Bible codes).[1]

In the life sciences there were scholars who studied the medicinal and commercial value of plant products. Herbals were part of the medical curriculum in the Middle Ages, with the bulk of medicinal products for treating the sick derived from plants. Also dyes for fabric came from plant products like woad or animal products like royal purple from snails along the Phoenician coast. The extraction, purification, and modification of techniques to make these effective was part of that ancient tradition of applied science, but most of the knowledge was passed through families involved in what later were called the guilds of the Middle Ages. Some of this knowledge was assembled by scholars like Aristotle and Galen. It is from those Greek and Roman sources that historians can grasp insights into how the ancients saw their world.[2]

Many saw their universe through the filter of their religious beliefs. This was certainly true of those who wrote the books of the Old Testament. Rainbows were signs or blessings or acknowledgements from God. Natural disasters, as we gather when reading Homer's *Odyssey*, were sent by deities who used humans to play out their divine rivalries and petty feuds. It was a god who churned the seas during storms. It was a god who tumbled rocks during an avalanche. It was a god who tossed lightning bolts or who crashed an immense anvil to create thunder. In the biblical tradition, it was transgressions against God that led to pestilences, plagues of locusts, and the parting of the seas to later smash together to destroy a hectoring army or to engulf the world in a flood. Some used sacrificed animal livers as auguries or means of predicting the future. Others, who were not guided by such direct religious sources for natural phenomena, created theories of health based on impurities or toxins that needed to be purged. Galen proposed four fluids or humors that he designated as blood, yellow bile, black bile, and phlegm. If they were in balance and not contaminated with toxins, the person was healthy. The ill had impurities or imbalances, correctible by bloodletting, purging, enemas, cupping, leeches, and other procedures. The functions of most organs in the body were unknown. There was no knowledge of cells, genetics, biochemistry, metabolism, or fertilization by gametes.[3]

How Is Knowledge of the Life Sciences Organized?

Today we organize a science in several ways. For the life sciences, the fields of botany (plant science) and zoology (animal science) made the first division. As noted earlier, botany was primarily a part of medicine. Zoology was separate from veterinary medicine or from farming with domesticated animals. There was no theory for why some animals can be domesticated and most remain wild and do not breed in captivity. Aristotle classified animals as warm-blooded and cold-blooded. He recognized four-legged organisms as a group. He studied embryos in chick eggs and concluded (correctly) that embryonic development was epigenetic—that is, form emerged gradually and was not simply a process of enlargement of a preexisting form. Form was somehow imposed on disorganized matter provided by the egg of the chicken. Aristotle believed the form to be present in the semen of the rooster, but he did not know how it worked.[4] The status of botany and zoology changed after the late 19th century when Louis

Pasteur, using a microscope and experimentation, showed microbial action in fermentation, putrefaction, and disease. Robert Koch established the techniques for studying these microbes and classifying them. The field of microbiology was added to universities.[5]

The attempt to classify shared and distinct features of organisms fell into the fields of anatomy and taxonomy. Anatomical study isolated the organ systems and determined some of their functions. The functional aspects that were not mechanical, like muscles and body movement, were shifted into a field called physiology. This was formalized by calling the structural basis of life morphology and the functional basis of life physiology. As microscopy was introduced to medical schools in the 19th century, the morphology of tissues became the science of histology. As stain technology and optics improved for microscopy, the details within the nuclei of cells led to another branch, cytology, which worked out cell division and gamete formation. Embryology also embraced microscopy in the 18th and 19th centuries and became a separate field.

In the late 19th and early 20th centuries, new fields emerged. Genetics studied heredity, especially through breeding analysis.[6] Ecology studied the relation of organisms to their environments and habitats. Systematics studied classification (taxonomy) in relation to evolution. Some fields combined to explore common interests. Thus, comparative anatomy wedded taxonomy to evolution.[7] Physiology spun off specialties like endocrinology, the study of hormones, in the early 20th century. The last fields to develop were biochemistry and molecular biology.[8] Biochemistry revealed biochemical pathways and thus fused genetics to biochemistry. Molecular biology fused the chemical and physical structure of molecules to their biological functions, especially after the discovery of DNA as genetic material that was physically organized as a double helix with an aperiodic sequence of nucleotides that made it the chemical basis of genes and their functions. This is just a sampling of dozens of specialty fields in the life sciences. There are probably about 50 such fields in health sciences and a similar number in the life sciences.

Do New Fields Emerge Suddenly or Gradually?

The purpose of my book is an exploration of those processes that lead to the emergence, fragmentation, union, and historical evolution of the life sciences. There are at least two major ways to interpret this process. In 1962, physicist and historian of science Thomas Kuhn (1922–1996) proposed a theory of paradigm shifts.[9] He classified most scientific work as “normal science.” In this process, an initial theory or paradigm is an incomplete puzzle and the business of most scientists is filling in the unexplored parts of the theory and looking for a consistency when new additions are placed, much like a jigsaw puzzle analogy. When things do not fit or there are outright contradictions (called anomalies), the puzzle begins to collapse, a crisis ensues, and the old paradigm fails; a new theory rearranges the components into a new paradigm. The new paradigm solves the anomalies and a new meaning is provided to the old vocabulary. Kuhn called this process a "paradigm shift." His classic example was the shift from the Ptolemaic to the Copernican system in which the Sun shifted from its central status as a planet around the Earth into a central star, the Earth got displaced from the center of the then-known universe and became a planet, and the planets all revolved around the sun. Our moon shifted from being a planet around the Earth to a satellite around a planet. Note that in this Copernican paradigm shift the names and functions may change but the components are the same. Nicolaus Copernicus (1473–1543) did not add a new technology (the telescope was later introduced for astronomers by Galileo). Astronomy is not an experimental science. What changed was the mode of thinking about the relation of the components of the night sky.

In contrast to this way of seeing scientific revolutions, I propose designating normal science as "incrementalism."[10] In this model, change takes place in small (occasionally sudden or more significant) additions. So too are the pruning processes that eliminate outmoded observations and interpretations. Both the paradigm shift and the incrementalism models use the term "scientific revolution." For the paradigm shift model, the revolution is primarily a theoretical one. For the incrementalism model that I propose, the revolution is one of innovation through experimentation, new technologies, or the emergence, fusion, or splitting of fields of knowledge.

In the chapters of this book, I will discuss the two models in relation to different fields of the life sciences to see those that fit Kuhn's 1962 paradigm shift model, those that fit the incrementalism model, and those that are not readily

Thomas Kuhn received his B.S., M.S., and Ph.D. degrees from Harvard while studying physics. He shifted to the history and philosophy of science and taught at Berkeley, Princeton, and MIT. His most famous work appeared in 1962 as *The Structure of Scientific Revolutions*. Kuhn's book had a powerful influence on scholarly fields, especially in the social sciences where many added relativity of ideas and consensus as the basis for paradigm establishment. Kuhn tried to reject such claims. In popular idiom, the term "paradigm shift" has become a synonym for anything of intellectual, scientific, or social importance.

explained by either model or that combine features of both models. I will also discuss Kuhn's later views on how scientific fields arise.[11]

References and Notes

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