Spontaneous Generation and Kuhn's Model of Scientific Revolution

Alyssa Hill

Thomas S. Kuhn's *The Structure of Scientific Revolutions* describes the cyclical process by which science develops. This process, far from one of slow, gradual accumulation, is a process of revolution in which one framework for scientific thought is continually displaced by another. Its beginning is marked by the establishment of a paradigm, which allows for normal science to occur. Normal science illuminates anomalies, which may be resolved under the established paradigm, shelved, or deemed significant enough to cause a crisis. If a crisis results, a scientific revolution soon follows, and a new paradigm is established. The process then repeats itself. An example that illustrates Kuhn's model well is the replacement of the theory of spontaneous generation with the theory of biogenesis, which revolutionized the field of microbiology.

Integral to Kuhn's model is the paradigm, a term that can be loosely defined as a framework for scientific thought. Importantly, the paradigm serves to guide scientific progress by providing scientists with a set of axioms upon which science may build. It also determines the legitimate questions, answers, and apparatus to be employed in scientific research. Explains Kuhn:

> On the one hand, [the paradigm] stands for the entire constellation of beliefs, values, techniques, and so on shared by the members of a given community. On the other, it denotes one sort of element in that constellation, the concrete puzzle-solutions which, employed as models or examples, can replace explicit rules as a basis for the solution of the remaining puzzles of normal science. (175)

In other words, the paradigm dictates to the scientific community both what is important to pursue and how to pursue it. A paradigm can be further defined by the way in which it develops over time:

> ...[A] paradigm is rarely an object for replication. Instead, like an accepted judicial decision in the common law, it is an object for further articulation and specification under new or more stringent conditions. (Kuhn 23)

Here Kuhn highlights the flexibility of a paradigm, which allows for both its application to novel scenarios and its evolution over the course of time. The definition of the Kuhnian paradigm can thus be abstracted into three elements: (1) it must represent a set of beliefs, values, and techniques shared by a given community; (2) it must serve as a framework through which scientific puzzles are viewed; and (3) it must be amenable to further articulation. With these in mind, the Kuhnian concept of paradigm can be mapped onto the theory of spontaneous generation, which dominated what was to become the field of microbiology until the nineteenth century.

The theory of spontaneous generation (also known as Aristotelian abiogenesis) was developed in the fourth century by Aristotle and held that living organisms may be spontaneously generated from nonliving matter, or *the inanimate may give rise to the animate*. In Book V of his *History of Animals,* Aristotle explains it as follows:

> So with animals, some spring from parent animals according to their kind, whilst others grow spontaneously and not from kindred stock; and of these instances of spontaneous generation some come from putrefying earth or vegetable matter, as is the case with a number of insects, while others are spontaneously generated in the inside of animals out of the secretions of their several organs. (115)

Aristotle goes on to explain the specifics of spontaneous generation within the many animal genera, referring to it over twenty times in the remainder of *History*. Among those animals listed as originating via spontaneous generation are cockles, clams, razor-fishes, scallops, hermit crabs, sea nettles, and sponges (132-134). However, as demonstrated in the above quote, it would be inaccurate to say that Aristotle believed that spontaneous generation was the sole mechanism by which living organisms arise. In fact, in *History*, Aristotle candidly speaks of copulation between the sexes of various animal species and its role in the production of offspring. It can thus be said that Aristotle saw two legitimate mechanisms for the origin of life: that of biogenesis and that of spontaneous generation.

Numerous natural philosophers and religious thinkers in the centuries to come subscribed to and applied Aristotle's theory of spontaneous generation, including theologian Augustine of Hippo, Catholic priest Thomas Aquinas, author Sir Thomas Browne, and poet John Milton (Hankins 127; Lankester 125; Wilkins 20-21). Perhaps the most interesting application of this theory, however, was to the origin of the Barnacle Goose, which had implications on religious fasting.

In line with the theory of spontaneous generation, the Barnacle Goose was thought to have originated from the Goose Barnacle, a crustacean that grew on the sides of ships (Lankester 117; Thorndike 213, 333). At the end of the twelfth century, medieval historian Giraldus Cambrensis wrote a precise account of the generation of the Barnacle Goose in Ireland:

> There are in this place many birds which are called Bernacæ; Nature produces them, against Nature, in a most extraordinary way. They are like marsh-geese, but somewhat smaller. They are produced from fir timber tossed along the sea, and are at first like gum. Afterwards they hang down by their beaks as if they were a seaweed attached to the timber, and are surrounded by shells in

> order to grow more freely. Having thus in process of time been clothed with a strong coat of feathers, they either fall into the water or fly freely away into the air. (Lankester 120)

Due to its aquatic origins, the Barnacle Goose was considered a fish rather than a fowl, which permitted its consumption during Lent. Sir Edwin Ray Lankester explains this loophole in *Diversions of a Naturalist*:

> I think that this identification was due to the exercise of a little authority on the part of the clergy in both France and Britain, who were thus enabled to claim the abundant "barnacle goose" as a fish in its nature and origin rather than a fowl, and so to use it as food on the fast-days of the Church. (118-119)

It is at this point that the theory of spontaneous generation begins to reveal its paradigmatic nature as dictated by Kuhn's model of scientific revolution. The first element of the previously-established definition for paradigm is that it must represent a set of beliefs, values, and techniques shared by a given community. This is met in that the theory of spontaneous generation was a generally accepted principle, which is demonstrated by its various proponents (a few of which are listed above) and by its application to the origins of the Barnacle Goose which ultimately set a precedent for an entire religious community. The second element of the definition—that the paradigm must serve as a framework through which scientific puzzles are viewed—is met in that the theory of spontaneous generation was the framework through which the origin of the Barnacle Goose was observed and understood. Finally, the third element—that the paradigm must be amenable to further articulation—is met in that the solution to the Barnacle Goose puzzle further articulated the theory of spontaneous generation by showing that it fit the observations of the natural world.

Having established via the Barnacle Goose example that the theory of spontaneous generation does in fact meet the criteria set forth for a Kuhnian paradigm, it is necessary to move on to the step in the Kuhnian model known as normal science. Normal science can be defined as the accumulation of knowledge under a given paradigm. During periods of normal science, scientists strive to confirm and further articulate a given paradigm, leading to significant scientific advancement. In *On Kuhn*, Hanne Andersen comments on this concept: "research of this kind is not aimed at calling forth new sorts of phenomena or at inventing new theories, but solely at increasing the success of the accepted theory" (21). Importantly, Kuhn's normal science is very similar to the traditional view of scientific progress, in which successive discoveries build atop one another, gradually leading to a more comprehensive understanding of reality. However, this analogy fails when considering continuity. Unlike the commonsense notion of scientific progress that continues indefinitely, Kuhnian normal-scientific truths accumulate only until the point of crisis, at which the truths become obsolete and the slate is thus "wiped clean."

One example of Kuhnian normal science conducted under the spontaneous generation paradigm has already been discussed above. Perhaps a better example than that of the Barnacle Goose, however, is that of John Needham's experiment conducted in 1745, in which the theory of spontaneous generation was formally validated. In this experiment, Needham showed that boiled broth became cloudy after sitting for a period of time. Needham observed his findings under a microscope: "My Phial swardm'd with Life, and microscopical Animals of most Dimensions, from some of the largest I had ever seen…" (Royal Society 638). Given that boiling was thought to eliminate all life forms from the broth, the only valid conclusion to be drawn from this experiment was that spontaneous generation had occurred, which is exactly what Needham reported. This experiment lends itself well to the Kuhnian concept of normal science. Rather than "calling forth new sorts of phenomena" or "inventing new theories," Needham sought to confirm and further articulate an already-established theory, a hallmark of normal science.

Both before and after Needham's experiments, evidence contrary to the theory of spontaneous generation was gathered by scientists such as Francesco Redi, Lazzaro Spallanzani, and most famously, Louis Pasteur. These evidences, under the Kuhnian model, are considered anomalies, which are defined as "the recognition that nature has somehow violated the paradigm-induced expectations that govern normal science" (Kuhn 52). These violations of expectation present themselves during periods of normal science, in which scientists eagerly pursue paradigm-confirming knowledge via theorization, observation and experimentation. The first example of an anomaly within the spontaneous generation paradigm is the experiment of Francesco Redi in 1668, which refuted the theory of spontaneous generation for large organisms —specifically maggots, which were thought to spontaneously generate from rotting meat. In his experiment, Redi divided six jars into two groups of three. Different objects were placed in the jars. Then one group was sealed with fine gauze and the other was left open, exposed to air. The following figure illustrates and explains the basic components of Redi's experiment (Csuros and Csuros 4):

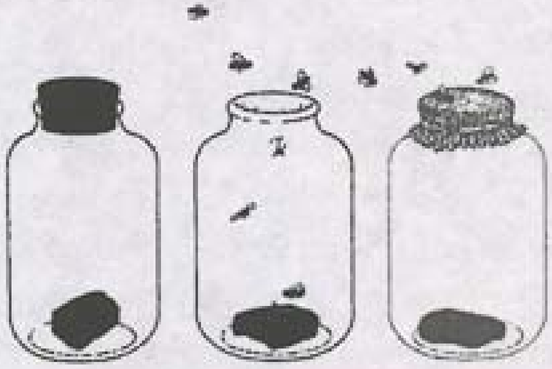

FIGURE 1.3 Redi's experiments refuting the spontaneous generation of maggots in meat. When meat is exposed in an open jar, flies lay their eggs on it, and the eggs hatch into maggots. In a sealed jar, no maggots appear. If the jar is covered with gauze, maggots hatch from eggs that flies lay on top of the gauze, but still no maggots appear on the meat.

After a few days, the jars were inspected for the presence of maggots. The open jars were found to contain maggots while the gauzed jars did not (Csuros and Csuros 4). Thus Redi successfully showed that maggots did not arise via spontaneous generation as was commonly thought. In fact, "a piece of gauze was enough to prevent the birth of fly larvae" (Debré 153). However, the paradigm of spontaneous generation was not immediately discredited:

> ...[T]he doctrine of spontaneous generation had been too long and firmly believed, to be surrendered merely because of the demonstrated falsity of its grounds. It was held to have the sanction of the Bible, which affirmed that bees were generated from the carcass of a dead lion: Dr. Redi was therefore called upon to defend himself against the charge of impugning Scripture authority. (Bastian and Strick 84)

The fact that the anomaly introduced by Redi's experiment did not shake the foundations upon which the spontaneous generation theory lay only lends credence to its success as a paradigm. It also adds legitimacy to the idea that not all anomalies are disturbing to the Kuhnian paradigm. Instead, there are three possible outcomes of an anomaly, as discussed in *The Structure of Scientific Revolutions*.

Under Kuhn's model, anomalies may be resolved under the established paradigm, shelved, or deemed severe enough to cause a crisis, ending in their resolution within a new paradigm. Redi's anomaly was neither resolved under the established spontaneous generation paradigm (as the two were simply incompatible) nor resolved under a new paradigm (as it did not lead to a crisis). Thus, it must be considered a shelved anomaly. Interestingly enough, it would take almost another two hundred years for the anomaly to finally be resolved under a new paradigm.

Experiments in the centuries following Redi continued to produce results that contradicted those expected under the spontaneous generation paradigm. For instance, in 1768, skeptic Lazzaro Spallanzani repeated the experiment of John Needham with a few minor, but critical, adjustments:

> Spallanzani…conducted further and better experiments in which he continued the boiling for much longer periods and carried out the boiling in previously sealed vessels, thus initiating the use of steam under pressure as a sterilizing agent. (Collard 3)

As Spallanzani had predicted, no microbial growth occurred. He thus concluded that microbes travelled through the air, and that allowing the broth to contact the air resulted in microbial contamination. It was this contamination that resulted in the growth observed by Needham. This conclusion both refuted the theory of spontaneous generation and paved the way for the coming experiments of Louis Pasteur (Collard 4). However, like the anomaly illuminated by Redi's experiment in 1668, Spallanzani's anomaly was ultimately shelved.

In 1862, Louis Pasteur finally laid the theory of spontaneous generation to rest and resolved the anomalies introduced by Redi and Spallanzani so many years before. After studying the works of Redi and Spallanzani, Pasteur, in a fashion typical of a Kuhnian scientist entering a paradigm with a shaky foundation, began conducting science in a crisis state; that is, he was unsatisfied with the explanations for the origin of microorganisms and set about trying to disprove spontaneous generation.

Pasteur's research into spontaneous generation (and the eventual success of the theory of biogenesis) was made possible by a commission of scientists selected by the French Academy of Sciences, which sponsored a contest for experiments best proving or disproving the theory of spontaneous generation (Debré 158; Dunster 21). Louis Pasteur and Félix Archimède Pouchet, a leading proponent of spontaneous generation, competed for the 2,500-franc Alhumbert prize, though in the end Pasteur's experiment was the only one submitted for review (Debré 161). Louis Pasteur won the competition with his famous swan-neck flask experiment, the results of which he published in a paper entitled "Mémoire sur les corpuscules organisés qui existent dans l'atmosphère" in 1861. In *Louis Pasteur,* Patrice Debré describes the flasks employed by Pasteur:

> These vessels were all large and their necks were long, thin, inclined, bent back, rounded, or swanlike. Serving to keep the germs away from the receptacles, these long necks were perfectly suited to the conclusions Pasteur wanted to formulate. If one places a fermentable liquid into these vessels and then boils the liquid, and if one then deposits the vessel in a place where the air is still, the liquid will remain clear for months. (161)

As hypothesized, Pasteur did not observe microbial growth within the liquid medium in the swan-neck flask and thus concluded, like Redi had done with maggots and Spallanzani with microbes, that spontaneous generation did not occur. He summarized his findings in the Latin phrase *Omne vivum ex vivo,* saying: "I prefer to think that life comes from life rather than from dust" (Debré 161). Pasteur had finally disproven the theory of spontaneous generation.

It was at this point that the theory of biogenesis, presented by Rudolf Virchow in 1855, began to supplant the theory of spontaneous generation and take root as a Kuhnian paradigm, which is still in use today:

> [Virchow's] aphorism 'omnis cellula e cellula' (every cell arises from a pre-existing cell) ranks with Pasteur's 'omne vivum e vivo' [sic] (every living thing arises from a preexisting living thing) among the most revolutionary generalizations of biology. (Wysong 182)

The theory of biogenesis states that living organisms are generated only from other living organisms, or *only the animate may give rise to the animate.* Its acceptance as a theory was aided both by the experiments of Louis Pasteur, which disproved spontaneous generation once and for all, and by the cell theory proposed in 1839 by physiologist Theodor Schwann and botanist Matthias Schleiden. Unlike the spontaneous generation paradigm, the biogenesis paradigm was able to effectively explain the anomalies presented by scientists Redi, Spallanzani, and Pasteur.

Reflecting upon the events discussed, it becomes clear that the replacement of the theory of spontaneous generation with the theory of biogenesis follows the Kuhnian model of scientific revolution. Once the spontaneous generation paradigm had been established, normal science ensued, represented by both the Barnacle Goose example and the experiments of John Needham in 1745. Furthermore, during periods of normal science conducted under the spontaneous generation paradigm, anomalies arose. This is evidenced by the experiments of Francesco Redi in 1668 and Lazzaro Spallanzani in 1768, both of which yielded anomalous results that were ultimately shelved. Unlike Redi's and Spallanzani's experiments, however, Louis Pasteur's swan-neck flask experiment of 1862 produced results that led to the dismantling of the spontaneous generation paradigm. This breakthrough set in motion a scientific revolution that brought about the paradigm to which microbiologists currently subscribe: biogenesis.

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