From Cells to Cell Theory: What Would Kuhn Say?

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It was over 200 years after the discovery of cells when scientists and civilians finally abandoned the theory of spontaneous generation of life in favor of cell theory, the idea that all cells come from preexisting cells. Inherent in cell theory was the belief that all life therefore comes from all preexisting life. This radical shift in the way life was viewed at the time can definitely be considered a paradigm shift. Its implications were far-reaching and included theological thinking. The way individuals viewed life and the world around them was radically changed and a decision had to be made by everyone: should I believe in spontaneous generation or cell theory? It was a decision that was black and white. In order to accept cell theory, one must completely reject the theory of spontaneous generation. Furthermore, the effects of cell theory can even be seen today. For example, scientists and researchers use various cell lines to conduct research as well as to manufacture recombinant protein therapeutics in the biopharmaceutical industry. These cells lines would not have been created and would not exist if belief in spontaneous generation were still prevalent. The discovery of the cell by Robert Hooke, with contributions made by Anton van Leeuwenhoek, was necessary for this eradication of the theory of spontaneous generation in favor of cell theory, a change that Thomas S. Kuhn, philosopher and historian of science, would call a paradigm

shift. Implications of belief in cell theory can even be seen today with the constant and effective use of HeLa cells in scientific research.

Any great discovery has a story behind it. Robert Hooke started out as any young man did in England during the 1600s. He was studying at Oxford and trying to find his place in the working world. Years went by and he became an appointed member of the Royal Society of London: "As a result, in November 1662, Hooke at last emerged from the shadows, and was appointed to the post of Curator of Experiments, 'offering to furnish them every day, on which they met, with three or four considerable experiments" (Jardine 97). The Royal Society was a group of distinguished men in London who met regularly to discuss matters of medicine and science. Hooke's position within the society was to provide the men with a group of experiments every day that would ignite scholarly discussion. This was a very important part of Hooke's life in that it exposed Hooke to a variety of people who could appreciate his expertise as an experimentalist. He gradually became a prominent and trusted member of London society (Jardine 97). Furthermore, this position allowed Hooke to debut his exquisite drawing and artistic skills: "He could also produce delightful drawings. Hooke was justifiably proud of his skills as an artist" (Jardine 88). These skills would prove to be highly useful and important in most of Hooke's life.

On September 2, 1666 tragedy struck in London. The Great Fire consumed most of the city, but Hooke was a major figure in the task of rebuilding the city: "Once the Corporation committed itself to rebuilding to the existing property lines (with some significant street-widening), Hooke's intimate knowledge of the streets he had walked two or three times a day became an invaluable asset" (Jardine 140-141). He made many valuable and important decisions immediately following the destruction of the city, which further

increased his prominence in London society. He was quickly becoming a well-known Englishman. Sometime before the fire, Hooke had published his microscopical findings in a piece of work entitled *Micrographia* in 1665.

In this book, Hooke is known to have made the discovery of a cell, which was aided by the use of a microscope. A common misconception is that Hooke also invented the microscope: “Microscopes by this time had been around for a generation or so, but what set Hooke’s apart were their technical supremacy” (Byrson 374). Before Hooke, single-lens microscopes were more widely used, but Hooke created and perfected a compound lens microscope, which he found more comfortable to use (Jardine 181). After the Great Fire of London, Hooke received a letter from a Dutch diplomat Huygen, which included numerous drawings prepared by microscopist Anton von Leeuwenhoek. In Huygen’s letter included praise for Hooke’s work, an introduction to the work and drawings of Leeuwenhoek, and a request for Hooke to establish a correspondence between himself and Leeuwenhoek, which Hooke initially turned down. “This was a chance for Hooke to secure international patronage, and to use *Micrographia* to advance his career beyond the somewhat claustrophobic circle of London virtuosi” (Jardine 181). Hooke was therefore familiar with the work of Leeuwenhoek, who observed and described single-celled organisms as “animalcules”.

Leeuwenhoek differed greatly from Hooke in many ways that likely contributed to his incomparable success. First off, Hooke had natural artistic abilities, which allowed him to expertly draw and represent the things he observed in his compound microscope. Leeuwenhoek, on the other hand, did not have those beautiful drawing abilities and actually had to employ local artists to draw was he saw in the microscope (Jardine 182). This probably had a negative effect and led to Hooke being more successful and prominent.

Secondly, Hooke decided to publish his work in a book to be bought and sold by anyone. Leeuwenhoek, on the other had failed at publishing possibly because he just was not interested in being published. The only documentation of Leeuwenhoek's discoveries that exist today is the letters he sent as correspondence between himself and Hooke via the Royal Society. Either way, both microscopists were similar in one important way: they utilized a fascinating and complicated tool to make profound discoveries about the intricacies of life. Hooke himself says in *Micrographia*, "And by the help of *microscopes*, there is nothing so small, as to escape our inquiry; hence there is a new visible world discovered to the understanding" (Hooke 8). The use of the microscope was essential to both of these men, for they were able to observe the previously unobservable. Furthermore, the use of the microscope contributed to the final overthrow of the theory of spontaneous generation: "They examined not with the mind's eye, but with the microscope. By observing,… [they] struck a powerful blow against the theory of spontaneous generation" (Farley 4).

Fast forward into the next century. The discoveries made by Hooke and Leeuwenhoek in the 1600s were well known. Cells were an entity of life and had been confirmed to exist in ways Hooke could not have imagined. Now that scientists knew what cells were, the next question was: Where do they come from? Up until the ingenious experiments of Louis Pasteur, scientists were adamant that life arose spontaneously, by pure chance: "Basically, however, all proponents of spontaneous generation believe that some living entities may arise suddenly by chance from matter independently of any parent" (Farley 1). Farley's book covers the discussion of spontaneous generation from Descartes until when the theory was fully disproved in the 1900s. The controversy was two sided. There were those people who believed in spontaneous generation and wanted to perform experiments that

would prove spontaneous generation. They would tend to adjust the theory of spontaneous generation in response to experiments performed that seemed to disprove the theory. For example, in 1668 Francesco Redi performed a series of experiments attempting to disprove the theory of spontaneous generation. He had two jars with raw meat in them. In one jar held the meat in the open air, and as a result maggots grew on the raw meat. In another jar, the meat was sealed from the air, and no maggots grew on the jars. As a response, the proponents of spontaneous generation responded that air was necessary for generation to occur.

John Needham performed another notable experiment in 1745 that seemed to lead to the conclusion that spontaneous generation of bacteria does occur. He boiled a flask of chicken broth, then sealed the flask and observed microbial growth. The idea here was that heating the flask would kill off anything living in the chicken broth that could potentially give rise to new bacteria. The main problem with his experiment was that the flask was exposed to the air for some time between boiling and sealing during which bacteria from the air entered into the flask. In 1768, Lazzaro Spallanzani performed a similar experiment that differed in one important way. He boiled chicken broth in a flask that was already sealed and observed no bacterial growth. Proponents of spontaneous generation again responded that there was something in the air that was necessary for spontaneous generation.

Pasteur finally came up with a revolutionary experimental method to appeal to all of the previous arguments. He poured nonsterile broth into a flask, and then bent the neck of the flask into a "swan-necked" flask by heating the glass. The liquid inside the flask was still opened to the air, but at the same time microorganisms and dust could not get past the bend in the neck of the flask and reach the broth: "Pasteur concluded from these experiments, that the atmospheric dust has been captured in the sinous extensions and that the necks has thus

prevented the contents of the flasks from being contaminated" (Farley 105). He boiled the broth and found that it remained sterile for a long time. He then went on to prove that the broth could support growth by tipping the flask so that the dust trapped in the neck contacted the sterile fluid. This work of Pasteur was essential for the final blow to spontaneous generation. However, it could not have been accomplished without the men that came before Pasteur. This story "seems to illustrate vividly how a naïve and antiquated myth can be overthrown by the persistent application of experimental method. The story and its moral have become classics" (Farley 2). This story also illustrates how proponents of a theory will seem to adjust the theory in response to anomalous observations in order to make observations meet expectations.

Thomas Kuhn was a historian and philosopher of science and is most well known for coining the term "paradigm shift" as a way to describe a scientific revolution. In his most prominent work, *The Structure of Scientific Revolutions*, he describes in intricate detail the process of revolutionary change and the many aspects involved in a paradigm shift. Kuhn defines revolutions as "episodes in which a scientific community abandons one time-honored was of regarding the world and of pursuing science in favor or some other, usually incompatible, approach to its discipline" (Kuhn, *Tension* 226). Kuhn says that in between paradigm shifts, science progresses in a steady manner and all research that is conducted is only meant to increase the scope of available knowledge. Kuhn calls this period "normal science". He says: "Normal science, the activity in which most scientists inevitably spend almost all their time, is predicated on the assumption that the scientific community knows what the world is like" (Kuhn, *Structure* 5). Normal science is not meant to create paradigm changes: "Normal science does not aim at novelties of fact or theory and, when successful,

finds none" (Kuhn, *Structure* 52). However, normal science will eventually and inevitably give rise to a paradigm change. Within a normal science tradition, scientists will eventually observe an anomaly that differs from their expectations. This anomaly usually will be incorporated into the existing theory using what Kuhn calls ad hoc adjustments: "They will devise numerous articulations and *ad hoc* modifications of their theory in order to eliminate any apparent conflict" (Kuhn, *Structure* 78). The theory will be adjusted to agree with observations.

Eventually the theory becomes too complex due to multiple adjustments, and a period of crisis will ensue: "The emergence of new theories is generally preceded by a period of pronounced professional insecurity" (Kuhn, *Structure* 67). The existing theory is under intense scrutiny while the anomalies present are examined in detail. Eventually, a new theory will emerge that will be radically different from the previous theory. Kuhn tells his readers that this theory will not be immediately accepted because the public and the scientific community will be resistant to the new theory: "Novelty emerges only with difficulty, manifested by resistance, against a background provided by expectation" (Kuhn, *Structure* 64). Once one chooses to accept the new theory, it will require complete rejection of the old theory: "The decision to reject one paradigm is always simultaneously the decision to accept another, and the judgment leading to that decision involves the comparison of both paradigms with nature and with each other" (Kuhn *Structure* 77). Kuhn also believed that for a new paradigm to be accepted, it must be better than its competitors. After the new theory is accepted as true, the period of normal science resumes and the process can potentially repeat itself over again.

The transition from the theory of spontaneous generation to cell theory would undoubtedly conform to Kuhn's idea of a paradigm shift. This shift is characterized by anomalies, adjustments, a period of crisis, as well as a completely radical new theory. As just mentioned, Kuhn believed that acceptance of a new paradigmatic theory required complete rejection of the old theory. Cell theory stated that cells arise primarily from preexisting cells while spontaneous generation stated that all life arises spontaneously and basically from nothing. These two theories are completely opposite and belief in one consequentially means rejection of another. Once the scientific community during the time of Redi, Needham, Spallanzani, and Pasteur recognized that the theory of spontaneous generation was under question, a decision had to be made. Kuhn would say that the decision was black and white between these two theories. He would also recognize the fact that the community would be resistant to this radical new theory and would make the decision slowly. Kuhn also says: "To reject one paradigm without simultaneously substituting another is to reject science itself. That act reflects not on the paradigm but on the man" (Kuhn, *Strucutre* 79). Kuhn would say that if a man stopped believing in spontaneous generation but failed to accept cell theory, he would therefore be choosing to reject science as a whole. This revolutionary shift can be characterized as a paradigm shift according to Kuhn because the two theories of spontaneous generation and cell theory are radically different and in complete opposition of each other.

Kuhn would further agree that the shift from spontaneous generation to cell theory is paradigmatic because it had significant wide-reaching affects and altered the current worldview of the time. Kuhn says: "paradigm changes do cause scientists to see the world of their research-engagement differently" (Kuhn, *Structure* 111). He says that when a paradigms changes, the world changes with them. A good paradigmatic shift brings about a

change in the way the world is viewed that extends outside of the scientific sphere. Kuhn says that after a scientist has learned to see the world differently after a revolution, the world "will seem … incommensurable with the one he had inhabited before" (Kuhn, *Structure* 112). The two worlds will not be in agreement with each other. If Kuhn were to analyze the revolution of cell theory, he would argue that it is paradigmatic because of the way it changed how the world was viewed.

The theory of spontaneous generation had many theological implications. A "preexistence" theory arose as a way to explain random occurrences of worms inside the human body that caused disease. This theory stated that a "seed" of worms preexisted inside the human species since the beginning of time and would lead to disease. "This theory, in which Adam not only contained all of mankind-to-be but also all his worms-to-be… presented an awful theological dilemma" (Farley 20). Theologically, we believe that God created the animals before he created humans. Therefore, logically, the worm could not have been created within the body of Adam. However, Christians began to support this theory in opposition to the theory of spontaneous generation, which became associated with materialism and atheism: "As a result defense of preexistence and attacks upon spontaneous generation became a tenet of the Christian faith" (Farley 29). The doctrine of preexistence, which can be considered an early cell theory, offered the possibility that there was a higher power guiding the generation of all life, rather than life being created spontaneously and randomly. The controversy over spontaneous generation definitely extended outside of the scientific community.

Furthermore, the theory of spontaneous generation can be seen to contradict certain laws of nature. Nature was supposed to be pure, simple, and immutable. If organisms could

arise purely by chance, then there was no cause or pattern to existence. That seems to contradict what can be observed in nature. Organisms are not a random hodgepodge of individuals but rather are created with certain specificity: “Spontaneous generation seemed to be at odds with this concept of nature. That organisms could arise spontaneously ‘by chance’ implied that such occurrences were without cause. They were accidental, exceptional, unlawful, unknowable events, which ran contrary to the widely held concept of the universality of natural law” (Farley 11). It is this complexity of life and pattern of life that makes spontaneous generation highly improbable. The implications of the theory of spontaneous generation clearly affect all aspects of life because the controversy is about how life is generated. Kuhn would see the revolution from spontaneous generation to cell theory as a change of worldview because it affects how we see life. A world in which life arises spontaneously is radically different from a world in which life arises from all preexisting life.

The theory of spontaneous generation follows Kuhn’s idea of ad hoc adjustments to a current paradigm. The paradigm of spontaneous generation prevailed for centuries, but as time went on and instrumentation became more advanced, scientists were able to uncover more and more anomalies present in the theory. Their better experimental methods and observational techniques provided on opportunity for seeing an anomaly present within the theory. Kuhn says that when anomalies arise within a paradigm they will likely be incorporated into the existing theory. The existing paradigm will be adjusted and modified in ways to support the new anomalous observations. Eventually, after enough adjustment, the expectations provided by the theory will meet the anomalous observations. For example, proponents of the theory of spontaneous generation modified the theory in order to accommodate observations. The experiments performed by Redi and Spallazani

demonstrated that in a jar sealed from the air, no generation of life occurs on rotting meat or chicken broth. Proponents of spontaneous generation adjusted the theory to match these anomalous observations by stating that there was some special quality or substance in the air that provided an essential ingredient for life: "On the other hand, those supporting the doctrine were always forced to justify an anomaly" (Farley 5). Kuhn says that these justifications eventually lead to a complex theory. However, in the case of spontaneous generation, this does not really occur. Fortunately, an intelligent experimentalist by the name of Louis Pasteur came along.

Even though Pasteur did make a significant contribution to the final elimination of the theory of spontaneous generation, Kuhn says that a paradigm shift cannot be attributed to just one person at one time. He says, "… discovery is a process and must take time" (Kuhn, *Structure* 55). Kuhn says that the revolutionary process is not usually completed by a single man, and not usually overnight (Kuhn, *Structure* 10). Kuhn would say that the paradigm shift from spontaneous generation to cell theory fits in with this idea. He would say that the work of those before Pasteur was still significant to the paradigm shift to cell theory. It is significant because if it were not for those before Pasteur, he would not have been able to come up with an ingenious experimental procedure in which all issues were met: "the sequence of events leading up to his own work stemmed mainly from the experimental work of Redi, Needham, Spallanzani…" (Farley 114). If it were not for those that worked before him, Pasteur would not have been aware of the ad hoc adjustments made to the theory. Therefore, it is really the work of all of these scientists that contributed to the revolutionary change, something that Kuhn would agree characterizes a paradigm shift.

It can also be argued that the work of Robert Hooke contributed significantly to the final formation of cell theory and that without his important discovery, cell theory might not exist. Kuhn believes in short that instrumentation is just as important as experimentation when working towards a scientific development. Kuhn says: "In short, consciously or not, the decision to employ a particular piece of apparatus and to use it in a particular way carried an assumption that only certain sorts of circumstances will arise. There are instrumental as well as theoretical expectations, and they have often played a decisive role in scientific development" (Kuhn 59). Using a particular instrument has a profound affect on scientific development and Kuhn would argue that the use of the microscope fits into this part of his theory. The microscope "revealed to an enchanted public a universe of the very small that was far more diverse, crowded, and finely structured than anyone had ever come close to imagining" (Bryson 374). The microscope heightened the senses so that individuals could observe parts of life that were previously unobservable. Hooke believed that the use of the microscope could eventually help to disprove the theory of spontaneous generation: "he believed that if microscopists looked hard enough they would discover the parents of some creatures whose birth had until then been regarded as spontaneous" (Inwood 74). Even Hooke was able to predict the coming revolution of cell theory, and he believed that the use of the microscope would aid in the downfall of spontaneous generation. Kuhn would definitely have a lot to say about this. He would likely comment that it makes sense that Hooke predicted the coming revolution. This tends to happen but is ignored because the time is not right for revolution to occur: "The solution to each of [the problems] had been at least partially anticipated during a period when there was no crisis in the corresponding science;

and in the absence of crisis those anticipations had been ignored" (Kuhn, *Structure* 75). Hooke's predictions were not noticed at that time, but were in fact correct.

Kuhn would also comment about the use of the microscope to extend the use of the senses. At what point is the microscope an extension of the user? At what point does it become an extension of our own senses? Kuhn would argue that we have to assume it is an extension of our own senses or else we would not be able to take our observations using the microscope as truth so that we can gather knowledge from it. Hooke, in his most popular work *Micrographia*, says: "And by the help of *microscopes*, there is nothing so small, as to escape our inquiry; hence there is a new visible world discovered to the understanding" (Hooke 8). He says that through the use of various instruments to aid in observation, things may come to be more fully discovered (Hooke 9). Kuhn would probably agree with Hooke's opinion on this matter. Kuhn says "Without the special apparatus that is constructed mainly for anticipated functions, the results that lead ultimately to novelty could not occur" (Kuhn, *Structure* 65). Special devices constructed for specific purposes are an important aspect of observation of anomalies. Hooke even went so far as to suggest that perhaps the other senses could be 'helped' by the creation of other inventions: "And as *Glasses* have highly promoted our *seeing*, so 'tis not improbably, but that there may be found many *Mechanical Inventions* to improve our other Senses, of *hearing, smelling, tasting, touching*" (Hooke 14). Hooke says that the use of these other mechanical inventions could potentially aid in the observation of the already visible world as well as "the discovery of many others hitherto unknown" (Hooke 22) that could reveal to us new worlds. But what does this mean for us today?

Henrietta Lacks was an African American woman of the lower class who lived in a tobacco-farming town in rural Clover, Virginia. After moving with her family up to the

Balitmore area, doctors at Johns Hopkins told her she had cervical cancer. She went to the hospital to receive treatment in the form of radium, and during which the doctor "shaved two dime-sized pieces of tissue from Henrietta's cervix" (Skloot 33) without her knowledge or her permission. These cells where given to a Dr. Gey, head of tissue culture research at Johns Hopkins (Skloot 30). They proliferated at an incredible speed, and survived longer than any other tissue culture cells that had ever been harvested. Quickly they spread from doctor to doctor through the mail or through personal deliveries. These doctors were performing experiments on them and conducting research to develop cures for a variety of diseases. Henrietta never knew anything about this and died shortly after in 1951 due to cervical cancer that had metastasized.

Henrietta's cells were harvested with the intention of looking for a way to grow immortal human cells in order to conduct research on cancer. Dr. Gey and his wife had been searching for a way to grow malignant (cancerous) cells outside the body for decades, so they would jump on any opportunity for human tissue: "The Geys were determined to grow the first *immortal* human cells: a continuously dividing line of cells all descended from one original sample, cells that would constantly replenish themselves and never die" (Skloot 30). The cells harvested from Henrietta Lacks' cervix indeed became these immortal cells that continued to grow on their own outside of the human body. Each HeLa cell used today in research is descended from that original sample from Henrietta's cervix, although the original samples from the 1950s are no longer alive. There is no way that this cell line could have been found if the community still believed in spontaneous generation. The Geys would not have been looking for an immortal cell line, because they would still think that life arises spontaneously. Therefore, the effects of the scientific revolution of cell theory can still be

seen today. If it were not for HeLa cells, we would not have an effective polio vaccine, amongst other things. This actually further proves the point that this revolution did indeed have far reaching effects.

HeLa cells are an important after effect of the belief in cell theory. It was only at the end of the 1860s that the theory of spontaneous generation was almost completely eradicated also Rebecca Skloot tells us that the Geys were searching for this immortal cell line for three decades before they found it in the 1950s in Henrietta Lacks. Not that much time had gone by between these two significant events. I believe that Kuhn would agree that this revolutionary change would be considered a paradigm shift in accordance with his philosophy. It has all the characteristics. The current paradigm went through a period of ad hoc adjustments to incorporate anomalous observations. A crisis ensued within the paradigm of spontaneous generation through the experimental work of various scientists and the final discovery depended on the work of these scientists. Furthermore, the revolutionary change had far-reaching effects and changed the way the world was viewed at the time. The world would be a very different place today if we did not believe in cell theory. Many of the discoveries made and vaccines produced in the last 60 years have depended on the knowledge that all cells arise from preexisting cells.

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