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E. E. Just and Creativity in Science. The Importance of Diversity

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Abstract

Renowned biologist Ernest Everett Just (1883-1941) was an outspoken advocate for the classical embryologist's view of the cell; he believed that all the parts of the cell, but especially the cytoplasm, have important roles to play in the process of development, whereby a one-celled zygote becomes a many-celled animal. In opposition to geneticist Thomas Hunt Morgan, Just formulated a hypothesis for how the cell works in development, one that gave a more dominant role to cytoplasmic (instead of nuclear) factors. This paper argues that, in creating his hypothesis, Just applied insights from the African American intellectual community in which he was immersed, much as Charles Darwin applied insights from British political economist Thomas R. Malthus in formulating his theory of evolution by natural selection. This in no way diminishes the scientific validity of Just's (or Darwin's) hypothesis. Rather, it highlights Just's creativity and, as such, points to the importance of having diversity in science.

Keywords

Ernest Everett Just; History of Biology; Scientific Creativity; Diversity in Science

The early twentieth century biologist Ernest E. Just (1883-1941; Fig. 1) is best known for his detailed studies of the structural changes that occur in the eggs of marine invertebrates (e.g., sea urchins, sand dollars, various marine annelids) during fertilization (for reviews of Just's scientific work and its significance, see Manning 1983; Byrnes and Eckberg 2006; Crow, 2008; Byrnes 2009; and Byrnes and Newman 2014). Less well known is the fact that in the 1930s he played an active role in promoting the classical embryologist's holistic view of the cell. He championed the notion that all parts of the cell participate fully in the developmental process, a view that was in opposition to that of the newly emerging geneticists, who instead gave a dominant role to the nucleus. Striving to reconcile the two views, Just presented an explanation for how differentiation can occur in the early embryo. In direct contrast to pioneering geneticist T. H. Morgan's gene theory, he proposed that it was the cytoplasm and cytoplasmic factors, not the nucleus and nuclear factors (genes), which played the more dominant part. Although Just's theory, which he called the "theory of genetic restriction," was incorrect in denying a central role for genes in development, it nonetheless did have redeeming qualities that we can now appreciate. The recent rise of the

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field of epigenetics, which is concerned with the different ways that genes interact with extra-nuclear determinants (such as environmental factors) to bring the organism's phenotype into being (van Speybroeck 2002), has to some extent shifted our gaze away from the nucleus.

As we will see, Just's explanation of how the cell functions during development, focused as it was on nuclear-cytoplasmic interaction, now seems quite forward-looking. It also demonstrates his scientific creativity. After giving a biographical sketch of Just's life, I present the argument that these creative ideas originated from his engagement with the black intellectual community of which he was a part. I further argue that Just's story highlights the importance of diversity in science.

The argument that Just's intellectual milieu provided insight into how the cell functions during embryonic development is, I believe, a new one. Though broad and comprehensive in many ways (and therefore a great source of ideas for further exploration of Just), the biography of Just by Massachusetts Institute of Technology science historian Kenneth Manning does not explicitly discuss the topic of possible cultural influences on Just's work. The book contains passages describing Just's friendships with Alain Locke and Melville Herskovits, his participation at a 1927 conference at Yale on black education and race relations, and his general interest in anthropology (Manning 1983, pp. 151-152, p. 156, and p. 203), but it does not really delve into this topic. On the other hand, a 1988 book chapter by Scott Gilbert of the University of Helsinki and Swarthmore College does make a connection between Just's scientific ideas and his cultural milieu (Gilbert 1988). But, as I will point out below (see Discussion section), Gilbert casts the connection in a different light, and the conclusions he reaches are different from the ones I reach here.

Biographical Sketch¹

Born in 1883 in Charleston, South Carolina, E. E. Just attended the Colored Normal Industrial Agricultural and Mechanical College at Orangeburg (now South Carolina State University) and then Kimball Union Academy, a boarding school in Meriden, New Hampshire, from which he graduated in 1903. He entered Dartmouth College, graduating *magna cum laude* (the highest distinction bestowed that year) in 1907 as an esteemed Rufus Choate scholar with honors in sociology and history, among other subjects. While an undergraduate student, Just became interested in biology, especially zoology, and he conducted research under the guidance of Dartmouth professor William Patten, whose interests lay in the area of the anatomy and evolution of frogs and other vertebrates (as well as the limpet, a marine gastropod mollusk). Immediately after graduating from Dartmouth, Just accepted a faculty position at Howard University, the premier institution of higher learning for African Americans, in Washington, DC, where he quickly rose through the academic ranks, becoming a full professor in 1912. He chaired the Department of Zoology at Howard and, with help from the Rosenwald Fund, established a Master's program in that field.

¹Most of the material in this sketch comes from *Black Apollo of Science: The Life of Ernest Everett Just*, the excellent biography of Just by Kenneth R. Manning (Manning 1983).

Starting in 1909, Just began making annual summer excursions to the Marine Biological Laboratory (MBL) at Woods Hole, Massachusetts, where he worked under the apprenticeship of renowned embryologist Frank R. Lillie. Almost from the beginning his work was significant. His first paper (Just 1912) showed that the sperm entrance point determines the first cleavage plane in the egg of the marine annelid *Nereis limbata*. The body of work for his PhD, which he obtained from the University of Chicago in 1916, was based on his study of the breeding habits and the fertilization reaction of *Platynereis megalops*, a marine annelid similar to *N. limbata* (Just 1914, 1915). In the late 1910s and early 1920s, he extended this line of work to the sand dollar *Echinarachnius parma*, publishing a series of eight influential papers on the fertilization reaction in that species (for the first in this series, see Just 1919). While at the MBL, Just rose from student researcher to internationally respected scientist.

Just was known at Woods Hole and beyond for his uncanny ability to coax marine invertebrate embryos to develop normally, and many of his peers sought his advice on the proper handling of marine animal eggs and embryos. He compiled a set of “indices of normal development” based on a detailed examination of the structural changes occurring at the egg cell surface during fertilization; these allowed him to predict with near certainty whether or not development would be normal for a given egg. In 1939 he published a laboratory handbook, *Basic Methods for Experiments on Eggs of Marine Animals* (Just 1939a), which presented his deep storehouse of knowledge on egg and embryo handling.

While at Woods Hole, Just investigated the effects of a number of variables, including UV irradiation, hyper- and hypotonic sea water and temperature, on parthenogenesis (the artificial activation of the egg by nonspecific triggers) in marine invertebrates. It was this work in particular that led Just to challenge the prominent physiologist Jacques Loeb of The Rockefeller Institute for Medical Research in New York. Loeb, who famously had shown around the year 1900 that hypertonic sea water could induce egg activation, subsequently developed an improved method that involved the sequential treatment of the egg with two factors: butyric acid and hypertonic sea water. Carrying out his own experiments, Just systematically dismantled Loeb’s theory (Just 1939b, pp. 227-237). He showed that either factor alone could induce parthenogenesis, and that the order of treatment was completely inconsequential. But Just’s main disagreement with Loeb was not primarily with his experimental method. It was with Loeb’s belief that the egg was being activated by something that was *being done to it* by external factors. Just believed, in contrast, that these experiments in parthenogenesis were revealing a very important property of the egg cell and indeed all cells: their inherent capacity to respond to external stimuli, which he called their “independent irritability” (Just 1939b, p. 237). What was important was the egg and its properties, not what was being done to it.

Not content with simply studying the marine life around Woods Hole, in 1929 Just traveled to the Stazione Zoologica (now the Stazione Zoologica Anton Dohrn) in Naples to investigate the fertilization reaction in several European sea urchins (Just 1929a), and to determine whether or not the Mediterranean annelid *Nereis dumerilii* was the same as the North American species *Platynereis megalops*, as some had postulated. (It was not (Just 1929b)). Then, in 1930, he received an invitation by Max Hartmann, the German

protozoologist, to work for six months at the Kaiser-Wilhelm-Institut für Biologie near Berlin. An invitation of this kind extended to an American was unprecedented, but the Germans saw a connection between Just's work and their own. They wanted to know if his ideas about the importance of the cell cortex (the structured layer just beneath the cell surface, which Just called the ectoplasm) could be applied to protists such as *Amoeba proteus*, which they had been studying.

Altogether, Just made maybe ten excursions to Europe. In addition to his trips to Berlin and Naples, he traveled as well to Paris, to the Sorbonne, where he spent some time completing his second book, *The Biology of the Cell Surface* (Just 1939b), which brought his scientific work and his general ideas together as one synthetic whole. Of the seventy-plus articles he published over the course of his 30-year career, several were in German journals, including one in *Naturwissenschaften* that, for the first time, correlated changes in cell adhesiveness with developmental stage during the embryonic cleavage process (Just 1931). After 1936, Just's papers became increasingly philosophical (see Just 1936b, 1937, 1940). This reflected both his desire to apply his ideas about the importance of the cell surface more broadly and his increased willingness to challenge those American counterparts whom he felt were too reductionistic.

In 1938, bereft of funding and rejected by many of his American colleagues because of his opposition to their views and his gravitation toward European biology and ideas, Just began a self-imposed exile in Europe. He took up research at the Station Biologique at Roscoff, a small French fishing village in Brittany on the English Channel. But in 1940, the Nazis invaded both Paris and the strategically-located Brittany coastal region, including Roscoff, and Just was forced to leave. He returned to the United States and Howard University. However, in the fall of 1941 he fell tragically ill with pancreatic cancer and, by the end of October, he had died.

The Scientific Context

It is important to emphasize at the outset that a belief in a dominant role for the cell cytoplasm in development (as well as in heredity and evolution) was not unique to Just. This was a view that was embraced by a number of early 20th-century embryologists, including E. G. Conklin (1863-1952), Ross G. Harrison (1870-1959) and Just's own mentor at Woods Hole, F. R. Lillie (1870-1947). Even T. H. Morgan himself, prior to his "switch" to a more gene-centric view in the 1910s, took a similar position (see Gilbert 1998). For an appreciation of the larger historical context of the nucleus-cytoplasm debate and Just's place in it, see Sapp (1987, 2009). One thing that set Just apart from others, however, was the intensity of his defense of the embryologist's holistic view of the cell and organism.

The first half of the 20th century was an exciting time in the history of biology. Dramatic discoveries were being made in the study of biological development, inheritance and evolution, and E. E. Just was an important player on this scene. In the 1910s, Thomas Hunt Morgan, a Columbia University embryologist who won the Nobel Prize in medicine or physiology in 1933, began leading an effort to establish the new field of genetics. Based on his experiments on the fruit fly *Drosophila melanogaster*, Morgan proposed that physical

entities called *genes* are arranged in linear arrays on chromosomes in the nucleus. In his influential book *The Theory of the Gene*, Morgan called for the complete separation of the new field of genetics and the older one of classical embryology from which genetics had originated (see Gilbert 1988, Gilbert 1998 and Allen 2007). Morgan and the new cadre of geneticists believed that it was the nucleus that played the dominant role, and that genes were not only the units of inheritance, but also the controllers of all the events of the cell as well as the whole developmental process. This view was in opposition to that of classical embryologists such as Just, Conklin, Harrison and Lillie, who believed that all of the parts of the cell were important in inheritance and development. As the disagreement between genetics and embryology began to widen—creating a schism that has only recently begun to heal with the rise of evolutionary developmental biology—several people tried to broker reconciliation. One of these was E. E. Just. But, as it turned out, the “audacious” theory Just proposed as part of this effort, his “theory of genetic restriction,” was dramatically different from Morgan’s. It was overtly *cytoplasm*-centered (see Esposito 2013, pp. 134-143).

Just’s Theory of Genetic Restriction

In *The Biology of the Cell Surface*, Just presents his theory of genetic restriction to explain how genes and cytoplasmic factors interact during the developmental process. His goal is to explain the mystery of differentiation, that is, how the different types of cells that arise in the developing embryo can have such different characteristics. He articulates the difficulty that T. H. Morgan’s gene theory encountered in trying to explain the problem of differentiation: “For how could the genes be responsible for differentiation, if they are the same in every cell? Unless the geneticists assume that their genes are omnipotent, we cannot understand how the problem of differentiation can be solved by the gene-theory of heredity” (Just 1939b, p. 324). He goes on to explain how, according to his own experimental data, nuclear material increases over the duration of the embryonic cleavage process (Just 1936a). Building his argument, he observes that: “... no individual nucleus in any blastomere [a cell of the cleavage-stage embryo] at the end of cleavage ever vanishes. On the other hand the total quantity of nuclear substance ... is greater at the end than at the beginning of the cleavage-period” (Just 1939b, p. 308). He reasons that what is true for the cleavage process is true for the “whole course of development” (p. 308): nuclear mass increases overall. But out of what is nuclear material synthesized? Observing that the total amount of cytoplasm decreases during the same time period, he proposes that “nuclei are built up from the cytoplasm. So too their constituents, the chromosomes” (p. 310).

Just then states his theory: “The progressive differentiation of the egg during cleavage ... is brought about neither by the pouring out of stuffs by the chromosomes into the cytoplasm nor by segregation of embryonic materials [note that a rival theory at the time proposed that differentiation occurred via the selective re-distribution of egg-derived factors into different regions of the embryo, i.e., via segregation, during the developmental process] ... but by a genetic restriction of potencies through the removal of stuff from the cytoplasm to the nuclei” (p. 313). Put another way: “...all the differences, i.e., differentiation, that appear during development, rest upon cytoplasmic reactions. These are made possible through removal of obstacles by nuclei, hence, by chromosomes and genes. The nuclei by removal of substances release the activity of the cytoplasm in one direction” (p. 326). Thus, the job of

the nucleus in this or that type of cell is to selectively remove a subset of materials from the cytoplasm, “leaving others free. The free materials determine the character of the cell—as ectoderm, mesoderm, or endoderm ...” (p. 315)

In Just’s theory, then, the nucleus is more like a holding pen than the seat of power that the geneticists had imagined. Here, genes are relegated to second-class status; the important cellular players are the cytoplasmic agents, which, with help from genes, are freed to go about their vital tasks of giving the various cells their particular properties. Genes play the secondary role of absorbing this or that factor.

Consistent with Just’s theory, a recent finding in cell and developmental biology may indicate that chromosomes have the ability to absorb factors from the cytoplasm during development. Pagliara *et al.* (2014) discovered that the nuclei of differentiating embryonic stem cells tend to acquire a property known as “auxeticity,” that is, they expand when stretched, much the same way that a wad of balled-up paper expands when it is stretched. The physiological significance of this recent finding is unknown, but it could mean that the chromosomes of the cells can, in a selective sponge-like manner, absorb different sets of cytoplasmic factors as they change into various cell types (i.e., as they differentiate). If this is found to be true, then Just will have been more correct than one could have imagined.

Though forward-looking in its epigenetic orientation, Just’s theory was incorrect in denying a central role for genes in development. Indeed, from our vantage point of eighty years later, we can see cracks in the edifice of Just’s theory. We know now that differentiation occurs in part because of *differential gene expression* whereby proteins known as transcription factors enter the nucleus and bind to regions upstream of genes, thereby stimulating or repressing their transcription into messenger RNA. According to this model, the differential expression of the genes in cells of different tissue types can explain the cells’ different characteristics. Indeed, we have learned that there are almost electronic circuit-like patterns of expression of different sets of genes in different types of cells and during different stages of development. An example of this is the exquisite pattern of gene activation and repression that occurs during sea urchin development (for example, see Davidson *et al.* 2002).

Still, it is worth noting that even in this newer model of differentiation, the transcription factors, which are produced in the cytoplasm, must enter the nucleus and bind to regions of chromosomes in order to have their effects. In this respect, the model bears similarity to Just’s model, in which chromosomes “sequester,” or bind, cytoplasmic factors. Of course, the model differs from Just’s in that the binding of transcriptions factors to nuclear DNA actively elicits a response that emanates from the nucleus and has an effect in the cytoplasm. In Just’s model, the binding is entirely passive, and it is the factors that *remain* in the cytoplasm (not the ones that are sequestered) that determine cellular properties. As with most hypotheses, Just’s, his “theory of genetic restriction,” was only partially correct.

But differential gene expression is not the whole story either. We now know—post ENCODE 2012 (ENCODE stands for the Encyclopedia of DNA Elements; it represents an effort to determine the activity of all of the DNA elements in the human genome (ENCODE Consortium Project 2012))—that the situation is vastly more complex than we had

previously thought. Indeed, the cell's genome is a virtual hot bed of activity. Transcription factors are important, but so, too, are other features and processes such as: the particular three-dimensional structure that the chromatin has; the patterns of acetylation and methylation of histone proteins around which nuclear DNA is wrapped; patterns of methylation of the DNA itself; and the post-transcriptional modification (splicing, editing) or degradation/inhibition (by micro-RNAs) of messenger RNAs (see Allis, Caparros, Jenuwein and Reinberg 2015). Noncoding RNAs, that is, RNA transcripts that do not encode proteins, have also been found to play direct roles in regulating gene expression (Knowling and Morris 2011). Moreover, ENCODE has revealed that fully eighty percent of the DNA in the human genome is “functional” in the sense that either transcription factors or other regulatory proteins bind to it, or it is being actively transcribed into RNA (ENCODE Consortium Project 2012). Many of these transcripts are noncoding, and their roles are mostly unknown at this point.

The definition of the gene as a short stretch of DNA is being challenged. Some are saying that the basic unit of the genome should be the RNA transcript, not the DNA-containing gene (Brydon 2012). These scientists are attempting to redefine what a “gene” is. They are saying that, because the effective distance of separation between genes on chromosomes has largely disappeared, with gene “A” now almost continuous with gene “B”—this is because the genome is packed with functional sequence—it makes little sense to talk about a discrete DNA unit called a “gene.” Instead, these scientists argue, we should be talking about the gene as a collection of RNA transcripts that all relate to some common role or factor (Yong 2012).

What we are realizing based on ENCODE and other studies is that there is an extensive highway of interaction among factors originating in the cytoplasm and the “genes” located in the nucleus. Moreover, physical processes are increasingly being recognized as important (Lavelle 2014; Forgacs and Newman 2005). The old model in which there was a one-way flow of information from DNA to mRNA to protein that early 20th-century geneticists envisioned—the central dogma—is becoming increasingly untenable. It is looking more and more like Just was on to something. He was wrong about some of the details—no question about it—but absolutely right about the importance of nuclear-cytoplasmic interaction.

Just and Creativity in Science

We can see that E. E. Just had a conception of how the cell works that was in conflict with the emerging gene theory. But where did these bold ideas come from, and why was Just such a passionate champion of them? Why did he believe so strongly that all of the parts of the cell (but especially the cytoplasm) are important in the developmental process?

What I hope to show at this juncture is that Just's theory of genetic restriction was a product of his scientific creativity, and that, as such, it highlights one of the identities that scientists possess—that of creative agent. It also illustrates why diversity is important in science, because Just, unlike others, was uniquely positioned to advance the ideas that he did. I will argue that Just was singularly driven to challenge Morgan because he was able to see things differently than his peers. He had insights they did not have, ones which came from his

unique life experiences. He held convictions that were, yes, rooted in his experimental work, but which also were shaped by his own experiences. These gave him an intensity of purpose that his peers did not have.

But at this point the reader might ask, exactly how is science creative? Isn't it supposed to be an objective discipline that records observations and formulates theories based on results? Why is there a need for creativity, or unique insights, at all? These questions highlight a common misperception of how science works, one that is inaccurate because, as it turns out, science is very much a creative endeavor. Indeed, it is one of the most creative activities we can imagine.

Before we delve into a discussion of exactly how it is that science is creative, we can ask what some of the unique insights and convictions Just might have had were. Bear in mind that this is speculation (albeit speculation informed by the facts). Two observations are relevant at the outset: First, Just was African American and, second, he lived in the first part of the twentieth century, which was a time of great social change and intense intellectual and cultural activity in the black community. It was also a time of crushing discrimination and inequality. W. E. B. Du Bois, editor of *The Crisis*, the monthly magazine of the National Association for the Advancement of Colored People (NAACP) and a prominent sociologist at Atlanta University, in his writings and speeches, was fighting against assertions of racial inferiority that were being made by proponents of scientific racism at the time (Taylor 1981).

A Harvard graduate and close associate of Franz Boas of Columbia University, Du Bois countered these assertions with one of his own, saying that race was not biologically based, but rather was derived from the shared history and culture of a people (Smith 2007). He promoted solidarity among peoples of African descent around the world, and encouraged a sense of pride among African Americans. He talked about the "talented tenth" that included the foremost black intellectuals of the time (Du Bois 1903). E. E. Just, arguably the most famous African American scientist in the world at the time, would have been a member of the talented tenth. So, too, would Alain LeRoy Locke, a professor and colleague of Just's at Howard University who was known as the "philosopher of the Harlem Renaissance" and who was engaged in showcasing the great cultural vitality of African Americans (see Locke 1925).

A philosopher-turned-anthropologist, Locke argued that nations will prosper when they foster cultural exchange among the different racial or ethnic groups within and across their borders. He advocated for a kind of free trade between groups, emphasizing that the healthiest societal relationship is one in which each group is able to offer something of value to the other, and each group respects the other in its autonomy (Locke and Stewart 1992; Molesworth 2012). Just, a close friend of Locke's, was certainly familiar with his ideas. According to Manning, Just felt a close affinity for Locke and his views: "Harvard-educated and the first black American Rhodes Scholar, [Locke] was the kind of cultivated black man with whom Just felt comfortable. Locke's knowledge of black culture and history, his enthusiasm about the way blacks were shaking off 'the psychology of imitation and implied

inferiority' and achieving 'spiritual emancipation,' made an impression on Just" (Locke 1925, p. 4, quoted in Manning 1983, p. 152).

Just also was the one who invited Melville J. Herskovits, a student of Boas's, to visit Howard University's campus in 1924 (Manning 1983, p. 152). The year that Herskovits spent as a visiting scholar at Howard greatly influenced his now-famous book *The Myth of the Negro Past* (1941). Just kept up correspondence with Herskovits even after Herskovits left Howard (Just-Herskovits correspondence). Thus, the ideas about race relations and cultural dialogue that Du Bois, Locke, Boas, Herskovits and others articulated were known to Just. And the academic courses in sociology and history in which Just had excelled at Dartmouth certainly would have helped him to grapple with these concepts, which lay outside the realm of biology.

Might Just's notion of the "federalism of the cell" (Gilbert 1988) as opposed to a dictatorship coming from the nucleus, have been influenced by the concepts of race and race relations that were percolating within the black intellectual community at the time? Recall that the role of the nucleus during differentiation, according to Just's theory of genetic restriction, was to sequester factors from the cytoplasm, allowing the ones that remained to steer the cell in a particular direction. Genetic restriction removed certain factors from the cytoplasm, "*leaving others free*" (emphasis added; Just 1939b, p. 315). In other words: "Every cell in an organism becomes what it is because its cytoplasm has free its particular potencies whilst its nucleus binds all others" (p. 326).

Notably, the African American community was striving to break free of the chains of an oppressive and segregated American society. Though marginalized by more dominant (though not superior) members of society, it had many talents and many gifts to offer. Might Just's ideas about the important role of the cytoplasm during cellular differentiation have been influenced by these *sociological* concepts that were prominent at the time?²

An excerpt from Just's paper "On the Origin of Mutations" (Just 1932) will give us additional insight into his thinking on the relative roles of nucleus and cytoplasm: "No biologist today assumes that the nucleus can play a role in vital phenomena apart from the cytoplasm; both constituents of the protoplast are necessary. On the other hand, the conception of the cytoplasm as 'the kitchen of the nucleus' is fraught with consequences ill to the resolution of problems of the biology of the cell. However for the sake of analysis, though we firmly believe in the subsidiary role of the cytoplasm, it would seem worthwhile to examine this point of view: namely, that nuclear (and therefore chromosomal) behavior is secondary to that of the cytoplasm. I suggest that the cytoplasm determines nuclear behavior; the chromosomal behavior then is an expression of a more fundamental cytoplasmic activity" (Just 1932).

²At the same time, we would be remiss not to mention that Just was also deeply influenced by his European colleagues. Much of Just's time after 1929 was spent in laboratories overseas. He developed close relationships with European biologists, who by and large accepted the importance of his work, and he became fluent in several European languages, namely Italian, German and French. He even lectured in French at the Sorbonne in the late 1930s (see Manning 1983, p. 320).

Here we can visualize the cell as a microcosm of a larger human society in which groups that have been seen as marginal and on the periphery in fact have the more important role to play. This is a powerful sociological conception that likely informed Just's scientific ideas about the cell. Of course it goes without saying that any and all such conceptions—creations of the mind as it were—must be tested relentlessly using the scientific method, something at which Just was known to excel. Indeed, he was considered to be “a genius in the design of experiments” (Jeffery 1983). I will have more to say on this topic of scientific-hypothesis-as-creation-of-the-mind below.

Underneath this discussion of the possible influence of a nonscientific idea on the development of a scientific hypothesis, a pesky question lurks: is this a legitimate way to do science? Though ostensibly counterintuitive, the answer is nonetheless a resounding “yes!” It turns out that August Kekulé (1829-1896), the brilliant theoretical organic chemist, did science this way; physicist and mathematician Isaac Newton did, too; and so did Charles Darwin, co-discoverer of natural selection as a mechanism for evolutionary change (the other discoverer was Alfred Russel Wallace). Here is an excerpt from evolutionary biologist Francisco J. Ayala's book *Darwin's Gift to Science and Religion*, in which he discusses the ways in which ideas for hypotheses can arise: “Scientists, like other people, come upon new ideas and acquire knowledge in all sorts of ways: from conversation with other people, from reading books and newspapers, from inductive generalizations, and even from dreams and mistaken observations.” He adds that “[s]cientific thinking may be characterized as a process of invention or discovery followed by validation or confirmation” (Ayala 2007, pp. 188-189).

One of Ayala's arguments is that, although Darwin acted as though he followed what might be called the “inductivist canon” in which the scientist makes observations about nature and then devises a hypothesis based on those observations, in fact he did not, because this is not how science works. The truth is that “scientific hypotheses are *creations of the mind*, imaginative suggestions as to what might be true” (emphasis added; p. 186). Of course, the corollary to this (alluded to above) is that hypotheses, once constructed, must be subjected to “critical examination and empirical testing” (p. 188). The scientific community performs this examination and testing with rigor. During the process, the question it asks is “how does this measure up to reality?” Sometimes the hypothesis holds up well over time, as Darwin's Theory of Evolution by Natural Selection has. Sometimes it fails. Sometimes it holds up for a while, but then is found to be somewhat lacking and has to be modified. Sometimes it appears to be incorrect, but then is found to have some redeeming qualities (as the early twentieth century geneticist Richard Goldschmidt's hypothesis of macromutational “hopeful monsters” has; see Gould 1980, pp. 186-193. It turns out that Goldschmidt may have anticipated the discovery of what are known as homeotic genes and mutations). I believe that history will show that Just's Theory of Genetic Restriction falls into this last category: it appears to be flawed, but in fact will be found to be more correct than we now realize.

Upon reflection, then, we can see that it would not have been unusual for someone like Just to have come up with an hypothesis about how the cell works based on ideas percolating within his intellectual circle. Maybe Just was more exposed to certain ideas than his peers because he was around the ideas more. Further, maybe the ideas had more *immediacy* for

Just than for others. As a result, *he* would be the one to incorporate the ideas into a hypothesis, not someone else. In a similar way, Darwin was especially primed to incorporate the ideas of the Reverend Thomas Robert Malthus (1766-1834), the British political economist who believed that human populations rose and fell depending on their rate of growth and the availability of resources to sustain growth (Malthus 1826).

Darwin incorporated Malthus's ideas into his hypothesis of how evolution works (Darwin 1958): populations produce more offspring than can survive; nature selects among the various offspring, which differ in their characteristics; and those that are best adapted to the environment survive and reproduce. We may recall that Darwin had made that trip around South America on the USS Beagle; he had seen the great diversity and abundance of life everywhere he went; he had examined the fossils he encountered when he went ashore (Eldredge 2005). Moreover, he had spent a childhood romping through nature; he was a naturalist at heart. He, then, more than anyone else (except, perhaps, Wallace), was best prepared by circumstances and life experiences to make the particular contributions that he did make. His hypothesis of "descent with modification" has been tested relentlessly, and has survived the test of time. But, as we have seen, the seed that crystallized the hypothesis came from an idea in the field of *economics*. And so it was with Just, who likely got some of his ideas about how the cell works and about intra-cellular interaction from *social* theory.

Discussion: Why Diversity Is Important

As mentioned above, this work is not the first to recognize a connection between Just's scientific view of the cell and his cultural milieu. Scott Gilbert, a developmental biologist and science historian who likely was the first to cite Just's work in a college textbook (*Developmental Biology*, now in its 10th edition; see Gilbert 2013), also recognized a connection. Writing in 1988, Gilbert stated: "In viewing the embryo as a society where each cell is allowed to develop a particular potential, Just saw a model of a society where each group of people could express its potential once certain 'obstacles' were removed. It was a federalism that allowed the minorities to express themselves in a local fashion and, at the same time, contribute to the general welfare of the society. This was precisely the urgent political question that was being addressed by the leading black sociologists [such as W. E. B. Du Bois] of Just's time" (Gilbert 1988, p. 333). Gilbert then makes what I believe is an incredibly insightful comment: "The development of an organism is a history of its cellular interaction" (Gilbert 1988, p. 334). It was the realization of this fact, Gilbert says, that led Just to champion the cytoplasm and its outer rim, the ectoplasm, as the "prime mover of development, evolution, and intelligence (p. 334).

Recall that, for Du Bois, "race" was an expression of the shared history of a group of people. Thus, the racial identity of a people arose from its history, not from some set of inherent biological characteristics. This is as very powerful sociological concept, and I believe that it deeply informed Just in precisely the same way that Malthus's ideas informed Darwin. Gilbert has thus put his finger on the salient point regarding the connection between Just's scientific ideas and his cultural milieu.

However, the conclusion Gilbert draws from this connection is not that Just's cultural milieu influenced his science. Rather, his conclusion is in many ways the reverse: it is that Just projected his model of the cell onto society and used it to subtly champion both himself and the community of which he was a part. Moreover, Gilbert writes: "I believe further that [Just] made some psychological self-identification with the object of his meticulous observations. He thought the peripheral rim of cytoplasm beautiful, sensitive, creative, powerful, important, and disregarded. In short, his view of the cortex mirrored his view of the black in American society... . [T]he heroes of his book [*The Biology of the Cell Surface*] are both the cell surface and himself. By championing the cause of the cortex, he subtly championed his own" (p. 334).

Finally, Gilbert believes that Just casts his work within two narratives, those of "The Ugly Duckling" and "The Emperor's New Clothes" (Gilbert 1988, p. 340). In the first narrative, in which "the despised character is belatedly recognized as the most treasured," the hero is "alternately the cell surface and Just himself" (p. 340). In the second narrative, Just presents himself as the one who has the "keen eyes, unclouded judgment and personal integrity" that are needed to show the world that the genetic theory of mutation and development is incorrect (p. 340). In this view of Just, he is seen as someone who uses his vision of the cell as a way of promoting his own, and his people's, importance in society. Just's book, which represents his life's work, then becomes a tool for self-promotion motivated by a kind of self-pity based on feelings of having been victimized by society.

Although Gilbert otherwise shows great insight, I do not believe that his interpretation of Just's motivations is accurate. It is hard to imagine how an attitude of self-pity or self-promotion could have motivated Just to publicly challenge two of the giants of biology, T. H. Morgan and Jacques Loeb. Likewise, it is hard to see how this kind of attitude could have driven Just to persevere in the midst of crushing discrimination; psychologically this seems unlikely. Rather, I believe that it was a quest for biological truth that drove Just forward, because only a force of this magnitude would have been strong enough to allow him to endure what he did. Furthermore, I believe that the impetus for his striving—the ideas that crystallized his notion about how the cell functions in development—came in large part from the powerful sociological concepts of Du Bois, Locke and others.

All of this leads to my final argument, which is that diversity is critical for the scientific enterprise. Just had novel insights that arose in part from his particular life experiences. We do not know where the next Just will come from. This future person will have a unique set of experiences and come from a unique background. Who can say where an idea that turns into a hypothesis that revolutionizes our understanding of nature will originate? Who can say which scientist will be the one that is especially qualified to propose and champion that idea? To stifle diversity—or not to actively encourage it—is to diminish the creative engine of science (Byrnes 2013).

It is also important to emphasize that Just was *not* a great African American scientist—as if "African American scientist" is a special type, set apart from the others, and Just was an exceptional example of that type (see Kington 2013). He also was not a great scientist *who happened to be* African American—as if his ethnicity was somehow incidental to who he

was. Ernest E. Just was a great scientist *and* he was African American. His ethnicity informed who he was as a scientist and as a creative agent—in a powerful and positive way. It gave him a way of thinking about and seeing nature, a creative lens as it were, which was unique.

Realizing this about Just allows us to get to the core of what diversity is all about and why diversity is important for science. It is not really important for achieving a kind of balance of representation, although this is not a bad thing in and of itself. Diversity is important because we all lose in a fundamental way without it. Yes, we want to “weave a richer tapestry” in the biomedical and other sciences (Tabak and Collins 2011); we need to have representation from all of society’s various groups, in part because equal representation helps insure a more unbiased assessment of merit. But the need is more fundamental and more urgent than this: a diversity of ideas, which can originate from ethnic, cultural and other forms of diversity, is the very life blood of science because, without it, the stale ideas of the past might continue to circulate unabated, to the detriment of the scientific enterprise.

Conclusion

E. E. Just was unique in the history of biology. Shaped in part by his experiences in Europe, he nonetheless was very much a son of America. His novel ideas about how the cell functions in development were influenced by the cultural milieu in which he was immersed. But Just’s audacious theory of genetic restriction, forward-looking though it was in its emphasis on nuclear-cytoplasmic interaction, apparently did not leave a lasting mark on biology. There are likely several reasons for this. One is the dominance of the nucleus-centered gene theory, which shifted attention away from the cytoplasm, hence Just’s theory. A second reason is that, because Just was unable to obtain a faculty position at a research-intensive university (because he was black), which would have enabled him to work year-round, he was not able to train students to continue his work. A third is that, due to his outspokenness and his gravitation toward European biology, he was sidelined by his American peers. Treated as an outsider, his work was mostly ignored. Fourth and finally, simply by excelling, Just was challenging his peers’ notions about what African Americans should be like. This made them uncomfortable. Confronted with this challenge, many of them either downplayed the significance of his work, or simply ignored it.

But today Just’s work is increasingly being recognized as forward-looking and important. The late James Crow, a prominent American geneticist, said that Just was “one of the greatest biologists of the 20th century” (Crow 2008). Gerald Grunwald, a cell biologist at Thomas Jefferson University, called Just one of the “giants” of 20th century cell adhesion research (Grunwald 2013). As Just’s star continues to rise, we might do well to remember some of the lessons his life and career teach us. Diversity is essential, and unique life experiences often bring novel and valuable insights.

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References

- Allen, GE. A century of evo-devo: The dialectics of analysis and synthesis in twentieth-century life science. In: Laubichler, MD.; Maienschein, J., editors. *From Embryology to Evo-Devo: A History of Developmental Evolution*. MIT Press; Cambridge, MA: 2007.
- Allis, CD.; Caparros, M-L.; Jenuwein, T.; Reinberg, D. *Epigenetics*. 2nd. Cold Spring Harbor Laboratory Press; Cold Spring Harbor, NY: 2015.
- Ayala, FJ. *Darwin's Gift to Science and Religion*. Joseph Henry Press; Washington, DC: 2007.
- Brydon, E. In massive gene analysis, ENCODE data suggests "gene" redefinition. Cold Spring Harbor Laboratory. Aug 31. 2012 Retrieved from: <http://www.cshl.edu/Article-Gingeras/massive-genome-analysis-by-encode-redefines-the-gene-and-sheds-new-light-on-complex-disease>. Accessed 6 June 2014
- Byrnes WM. Ernest Everett Just, Johannes Holtfreter, and the origin of certain concepts in embryo morphogenesis. *Molecular Reproduction and Development*. 2009; 76:912–921. [PubMed: 19610071]
- Byrnes, WM. Opinion: A diverse perspective. Progress in science is dependent on the diversity of its workforce. *The Scientist*. Jul 29. 2013 Retrieved from: <http://www.the-scientist.com/?articles.view/articleNo/36733/title/Opinion--A-Diverse-Perspective/>. Accessed 2 September 2014
- Byrnes WM, Eckberg WR. Ernest Everett Just (1883–1941)—an early ecological developmental biologist. *Developmental Biology*. 2006; 296:1–11. [PubMed: 16712833]
- Byrnes WM, Newman SA. Ernest Everett Just: Egg and embryo as excitable systems. *Journal of Experimental Zoology B (Molecular and Developmental Evolution)*. 2014; 322:191–201. [PubMed: 24665037]
- Crow JF. Just and unjust: E. E. Just (1883–1941). *Genetics*. 2008; 179:1735–1740. [PubMed: 18711217]
- Darwin, CR. *The Autobiography of Charles Darwin (1809–1882)*. Barlow, N., editor. Collins; London: 1958.
- Davidson EH, Rast JP, Olveri P, Ransick A, Calestani C, et al. A genomic regulatory network for development. *Science*. 2002; 295:1669–78. [PubMed: 11872831]
- Du Bois, WEB. *The talented tenth*. In: Washington, BT., editor. *The Negro Problem: A Series of Articles by Representative American Negroes of Today*. James Pott and Co; New York: 1903.
- Eldredge, N. *Darwin: Discovering the Tree of Life*. W. W. Norton and Co; New York: 2005.
- ENCODE Consortium Project. An integrated encyclopedia of DNA elements in the human genome. *Nature*. 2012; 489:57–71. [PubMed: 22955616]
- Esposito, M. *Romantic Biology, 1890–1945*. Pickering and Chatto; London: 2013.
- Forgacs, G.; Newman, SA. *Biological Physics of the Developing Embryo*. Cambridge University Press; Cambridge, MA: 2005.
- Gilbert, SF. Cellular politics: Ernest Everett Just, Richard B. Goldschmidt, and the attempt to reconcile embryology and genetics. In: Rainger, R.; Benson, D.; Maienschein, J., editors. *The American Development of Biology*. Univ. of Pennsylvania Press; Philadelphia: 1988.
- Gilbert SF. Bearing crosses: A historiography of genetics and embryology. *American Journal of Medical Genetics*. 1998; 76:168–182. [PubMed: 9511981]
- Gilbert, SF. *Developmental Biology*. 10th. Sinauer Associates; Sunderland, MA: 2013.
- Gould, SJ. *The Panda's Thumb: More Reflections in Natural History*. New York: W. W. Norton and Co: 1980.
- Grunwald GB. A century of cell adhesion: from the blastomere to the clinic. Part I: Conceptual and experimental foundations and the pre-molecular era. *Cell Communication and Adhesion*. 2013; 20:127–138. [PubMed: 24245995]
- Herskovits, MJ. *The Myth of the Negro Past*. Harper and Brothers Publishers; New York: 1941.

- Jeffery WR. Ernest Everett Just (1883-1941): A dedication. *Biological Bulletin*. 1983; 165:487.
- Just EE. The relation of the first cleavage plane to the entrance point of the sperm. *Biological Bulletin*. 1912; 22:239–252.
- Just EE. Breeding habits of the heteronereis form of *Platynereis megalops* at Woods Hole, Mass. *Biological Bulletin*. 1914; 27:201–212.
- Just EE. An experimental analysis of fertilization in *Platynereis megalops*. *Biological Bulletin*. 1915; 28:93–114.
- Just EE. The fertilization reaction in *Echinarachnius parma*: I. Cortical response of the egg to insemination. *Biological Bulletin*. 1919; 36:1–10.
- Just EE. The fertilization reaction in eggs of *Paracentrotus* and *Echinus*. *Biological Bulletin*. 1929a; 57:326–331.
- Just EE. Breeding habits of *Nereis dumerilii* at Naples. *Biological Bulletin*. 1929b; 57:307–310.
- Just EE. Die rolle des kortikalen cytoplasmas bei vitalen erscheinungen. *Naturwissenschaften*. 1931; 19:953–1001.
- Just EE. On the origin of mutations. *American Naturalist*. 1932; 66:61–74.
- Just EE. Nuclear increase during development as a factor in differentiation and in heredity. *Anatomical Record*. 1936a; 64:32.
- Just EE. A Single theory for the physiology of development and genetics. *American Naturalist Suppl*. 1936b; 70:267–312.
- Just E.E. The significance of experimental parthenogenesis for the cell-biology of today. *Cytologia, Fujii Jubilee Vol*. 1937:540–550.
- Just, EE. *Basic Methods for Experiments on Eggs of Marine Animals*. P. Blakiston's Son and Co; Philadelphia: 1939a.
- Just, EE. *The Biology of the Cell Surface*. P. Blakiston's Son and Co; Philadelphia: 1939b.
- Just EE. Unsolved problems in general biology. *Physiological Zoology*. 1940; 13:123–142.
- Just-Herskovits correspondence. Northwestern University Archives, Melville J. Herskovits Papers, Series 35/6, Box 11, Folder 4
- Kington RS. Critic at large: On being an “African American Scientist. *The Scientist*. 2013; 27:28.
- Knowling S, Morris KV. Epigenetic regulation of gene expression in human cells by noncoding RNAs. *Progress in Molecular Biology and Translational Science*. 2011; 102:1–10. [PubMed: 21846567]
- Lavelle C. Pack, unpack, bend, twist, pull, push: The physical side of gene expression. *Current Opinion in Genetics and Development*. 2014; 25:74–84. [PubMed: 24576847]
- Locke, AL. The new negro. In: Locke, AL., editor. *The New Negro: An Interpretation*. Albert and Charles Boni; New York: 1925.
- Locke, A.; Stewart, JC. *Race Contacts and Interracial Relations: Lectures on the Theory and Practice of Race*. Moorland-Spingarn Research Center and Howard University Press; Washington, DC: 1992.
- Malthus, TR. *An Essay on the Principle of Population*. 6th. John Murray; London: 1826.
- Manning, KR. *Black Apollo of Science: The Life of Ernest Everett Just*. Oxford University Press; New York: 1983.
- Molesworth, C. *The Works of Alain Locke*. Oxford University Press; New York: 2012.
- Pagliara S, Franze K, McClain CR, Wylde GW, Fisher CL, Franklin RJM, Kabla AJ, Keyser UF, Chalut KJ. Auxetic nuclei in embryonic stem cells exiting pluripotency. *Nature Materials*. 2014; 13:638–644. [PubMed: 24747782]
- Sapp, J. *Beyond the Gene: Cytoplasmic Inheritance and the Struggle for Authority in Genetics*. Oxford University Press; New York: 1987.
- Sapp J. “Just” in time: Gene theory and the biology of the cell surface. *Molecular Reproduction and Development*. 2009; 76:903–911. [PubMed: 19396869]
- Smith, KK. *African American Environmental Thought: Foundations*. University of Kansas Press; Lawrence: 2007.

- Tabak LA, Collins FS. Weaving a richer tapestry in biomedical science. *Science*. 2011; 333:940–941. [PubMed: 21852476]
- Taylor CM. W. E. B. Du Bois's challenge to scientific racism. *Journal of Black Studies*. 1981; 11:449–460. [PubMed: 11635221]
- Van Speybroeck, L. From epigenesis to epigenetics: the case of C. H. Waddington. In: Van Speybroeck, L.; Van de Vijver, G.; De Waele, D., editors. *From Epigenesis to Epigenetics: The Genome in Context*. NY Academy of Sciences Press; New York: 2002. p. 61-81.
- Yong, E. Discover. Sep 5. 2012 ENCODE: The rough guide to the human genome. Retrieved from: <http://blogs.discovermagazine.com/notrocketscience/2012/09/05/encode-the-rough-guide-to-the-human-genome/>. Accessed 2 September 2014

Fig. 1.
E. E. Just, circa 1925. The Marine Biological Laboratory Archives..