Toward a Rhetoric of DNA

The Advent of CRISPR

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Abstract: The nucleic acid DNA, which contains an organism's genetic information, consists of a four-letter alphabet that has until recently been characterized as a read-only text. The development of a quick, inexpensive DNA targeting and manipulation technique called CRISPR, pronounced "crisper," though, has changed DNA from this arhetorical, read-only data set, as it has been characterized in the rhetoric literature to date, to a fully rhetorical text—one that can be not only read but created, interpreted, copied, altered, and stored as well. The Book of Nature, an idea with roots in antiquity but popularized during the nineteenth century, provides proof of concept in the form of an historical and theoretical context in which DNA can be viewed in this light. Once ensconced in the Book of Nature, DNA can no longer be considered a code; rather, it is a text. DNA text has structural components that are similar to those of traditional text, and now, with CRISPR, it also has purposes, audiences, and stakeholders. Given the enormous potential of DNA text for both good and ill, rhetoricians of science and medicine must participate in discussions of the complex literacy, policy, and ethics issues this new form of text brings about.

Keywords: DNA, CRISPR, Rhetoric of Science, Book of Nature, Text, Genetics, Literacy, Language

Introduction

A recently developed technique for the targeting and manipulation of DNA (deoxyribonucleic acid), called "clustered regularly interspaced short palindromic repeats" (CRISPR, pronounced "crisper"), has electrified the scientific, medical, and bioethics communities. CRISPR, which allows for quick, inexpensive targeting and alteration of DNA, raises profound questions about both the purposeful and accidental alteration of the human genome, of which DNA is the central component. On the one hand, successful purposeful manipulation of DNA could be enormously beneficial in the treatment of a vast array of hereditary illnesses and medical conditions. Indeed, CRISPR has already been used, in 2017, in a human embryo to excise a genetic mutation responsible for hypertrophic cardiomyopathy, a rare and often fatal condition that can cause heart failure in young people (Hong et al., 2017). More recently and controversially, in 2018, CRISPR has been used to treat twins for HIV resistance; the twins have since been born and are claimed to be healthy (Cyranoski & Ledford, 2018). On the other hand, the ability to intentionally manipulate DNA inevitably and legitimately leads to apprehension about designer babies, eugenics, and other abuses of genetic knowledge that are viewed by many as highly unethical. It is also inevitable that accidental alteration of DNA will occur and that unintended consequences or even deliberate alteration will transpire. Already, researchers have discovered that CRISPR use does not always go as planned; they have inadvertently used CRISPR to move or even delete DNA (Kosicki et al., 2018), resulting in potentially dangerous health consequences, including cancer (Haapaniemi, et al., 2018).[1]

Because of the intensified textual nature of DNA that CRISPR enables and that this article elucidates, rhetoricians can and should be deeply involved in research and policy discussions about genetics. Until the development of CRISPR, DNA and its four biochemical bases of adenine, guanine, cytosine, and thymine (A, G, C, and T, respectively) was largely a read-only text with a four-letter alphabet. The advent of CRISPR has changed that state of affairs

[1] The impetus for this article was a presentation at the University of California-Davis Health System Symposium entitled "CRISPR Technology: Responsible Discourse About Science & Ethics" in May 2016. I am grateful to Sarah Tinker Perrault and Meaghan O'Keefe for the invitation to speak at this event. I was introduced to the Book of Nature through the work of Samantha Harvey of Boise State University, and I am indebted to her for a number of discussions in which she shared important insight on this trope. I thank my York College of Pennsylvania colleague Gabe Cutrufello for commenting on an early draft of the manuscript and for suggesting that I send it to *POROI*, and I am grateful to Cristina Hanganu-Bresch of the University of the Sciences for helpful suggestions and an opportunity to speak on this topic at a meeting of the Philadelphia Writing Program Administrators in September 2017. I owe a debt of gratitude to Bill Voige of James Madison University, who introduced me to DNA in my college biochemistry classes and planned a pilgrimage to the Cavendish Labs at Cambridge University. Finally, I thank the anonymous *POROI* reviewer for her or his helpful recommendations; the manuscript is much stronger because of them.

dramatically and irrevocably. It is now possible to target, manipulate, and even create DNA-associated text, allowing for the full spectrum of discourse-related actions. Enter the rhetorician. We have reached a moment of Burkean transubstantiation with respect to text and DNA: the arrival of CRISPR means that text and DNA are one and the same (Burke, 1945).

A March 2017 joint report from the U.S. National Academy of Science and the U.S. National Academy of Medicine has endorsed the use of CRISPR for gene targeting and manipulation. This has led directly to treatment of the embryo with hypertrophic cardiomyopathy that I mentioned above. The report declares that the technique enables human gene manipulation to become "a realistic possibility that needs serious consideration" (Committee on Human Gene Editing, 2017, p. 188). Because the text of DNA can now be manipulated in a manner similar to that of traditional text, it is essential that we think of and study DNA as a form of rhetoric in an effort to resist the current, all-too-common practice, now exacerbated by CRISPR, of portraying DNA in a deterministic manner that fails to account for its complexity and uncertainty. Celeste Condit refers to this contradiction as an "aporetic stasis" characterized by the scientific and medical imperative to (*a*) learn more and more about human genes in an effort to control them but in doing so to (*b*) neglect to acknowledge their "probabilistic nature" and their potential to "remake the body itself" (1999, p. 348-349)—not to mention potentially all of the bodies of future generations. Rhetoric is, by definition, all about probability and negotiating conflict, and thinking about DNA as rhetorical is vital if we are to use CRISPR and its successors to develop gene therapies and other uses of DNA that are both effective and ethical.

In *The American Journal of Bioethics*, Meaghan O'Keefe et al. argue for the use of metaphors for CRISPR that meet three conditions: the metaphors must, first, capture the ethical complexity of CRISPR, second, accurately describe CRISPR, and, third, convey what is known and not known about CRISPR (O'Keefe et al., 2015). The ubiquitous metaphor of CRISPR as editing, the authors say, is problematic; the metaphor of CRISPR as targeting is much better because it more accurately describes what the technique actually does and better fulfills the above three conditions for good metaphors (O'Keefe et al., 2015). O'Keefe et al.'s work follows the analysis of metaphors used to describe genes more generally. Condit et al. find that shifting from a "blueprint" to a presumably more flexible "recipe" metaphor for genes fails to reduce impressions of genetic determinism (2002). In a related study, Parrott and Smith show that genetic determinism tracks more strongly with the "blueprint" metaphor than with an "instruction" metaphor (Parrot & Smith, 2014). I propose to extend this discussion to genes seen in the light of CRISPR.

What I want to add to existing work and related research on DNA and genes as cultural icons (e.g., Myers, 1990; Nelkin, 1996) is the argument that not only are the discursive characterizations of genes, DNA, and CRISPR important, but also that the speed and ease which CRISPR targets and manipulates DNA compels a realization that DNA is now no longer simply a nucleic acid and no longer simply a metaphor, be it a blueprint, recipe, instruction, computer program (Kay, 2000), code (Judson, 1992; Kay, 2000), or Swiss Army knife (Shipman, 2018). DNA is a text in and of itself. Even though, as O'Keefe et al. contend, the use of "editing"—a feature of text—as a metaphor for applications of CRISPR is unhelpful because it implies a degree of knowledge and control of DNA text that is not currently viable—a point with which I wholeheartedly agree—treating DNA as text, or at least prototext, enables us to capture CRISPR's epistemological contingency and moral complexity more fully. The purpose of this essay is to present such a proof of concept.

Theoretical Contexts

Characterizing the body broadly (i.e., not just DNA) as a text has a long tradition in rhetoric and composition studies and the humanities more generally. Kenneth Burke's notion of transubstantiation offers helpful ways to think about the unity of text and DNA. The idea that text and the physical world exist in concert, that they are bound together inextricably and impact each other profoundly, illustrates Burke's idea of rhetorical transubstantiation as "the representative moment of dialectic in general" (1945, p. 320). Still, it is Condit who performs the theoretical groundwork that characterizes the relationship between DNA and rhetoric most usefully. In a chapter entitled "The Materiality of Coding: Rhetoric, Genetics, and the Matter of Life," she uses DNA to build a theory of material rhetoric—one that captures features of both (post)humanism and physical materiality as they are commonly perceived—by demonstrating how DNA expands the scope of materiality to include form and relationships, rather than limiting the material to static physical characteristics such as DNA's biochemical components and processes (Condit, 1999). In the light of this perception, Condit considers the potential of DNA, by virtue of its coding function, to act rhetorically. She writes as follows:

> [T]hough we constitute discrete objects for ourselves through our language, all living organisms create [with the use of DNA] their own codes and coding units that stand outside our language games (though we may recode them into our language games as well). Human life is thus a constant rhetorical engagement between the human linguistic coding process and the coding processes of all living things (Condit, 1999, p. 344).

This statement captures the duality of the theory of material rhetoric that Condit advances. It shows that physical reality is undeniable but is also dynamic and, given the interdependence of all objects, relationship-based. On the rhetoric side, the statement asserts ontological potential on the part of text. Physical reality exists, then, but it is perceived, explained, and experienced rhetorically. Because of the diversity of rhetorics, differences in physical reality are made manifest. Condit concludes that "DNA acts with purpose because it acts to code an identity. But that does not get us all the way to 'rhetoric'" (1999, p. 345). Although purpose is present and is a necessary precondition for rhetoric, she continues, the coding occurs in the absence of any conscious awareness of alternatives and use of power. In other words, DNA creates and transmits information, but it does so without sentience. DNA cannot make decisions about when and where it can be used or about who will benefit (or not) from its use, nor can it consciously choose from a number of text creation, text editing, or text transmission options, or decide not to choose at all. Thus we have communication but not rhetoric, Condit argues, although she allows some room for the comparative or contrastive analysis of DNA code *between* species, which lends itself to "disparities of purpose that make power more operative than simple self-reference," with self-reference understood to be the function of DNA within a specific species (1999, p. 345, 347).

Condit's argument reinforces a similar line of reasoning from Burke, namely, that bodies are ultimately not "discursively constructed," as Debra Hawhee puts it in her analysis of Burke's work (2009, p. 166). Thus Burke is likely to have rejected the use of his transubstantiation concept as I have used it to unite body and text. However, Condit's characterization, which allows for the idea that communication takes place in the sense that information is transmitted, albeit without conscious purpose or attempted gain in power and/or resources, places her a step closer than Burke to the idea that DNA has rhetorical potential. Burke seems to disallow discourse (i.e., text) altogether in his understanding of the body.

Rhetorically, not all theories of relationships between text and organic matter have accepted Condit's and Burke's limitations. Beyond the human body, all living things have been conceived of as text, as with the Book of Nature trope, an idea introduced by St. John Chrysostom and St. Augustine during the late Classical era, which became popular much later, first during the early modern period and then in the nineteenth century, when the idea was explored by Francis Bacon, Charles Darwin, William Wordsworth, Samuel Coleridge, Ralph Waldo Emerson, Henry David Thoreau, and Walt Whitman (Harvey, 2013). Discussing the Book of Nature, or its close cousin, the Book of Life (Kay, 2000), Emerson, for example, declared that, "Nature is a language and every new fact we learn is a new word" (as cited in Harvey, 2013, p. 80). Reflecting the Transcendentalist appropriation of the idea, which linked the Book of Nature with a version of Christianity, Samantha Harvey defines the Book of Nature as "the concept that the physical landscape could be read as a book of spiritual meaning or alternative scripture in revealing God" (2013, p. 79). I am interpreting Harvey's use of "landscape" broadly here to include not only geological, topographical, and astronomical features, but also all of the biological and health-related components of life. In this sense, DNA is a part of the Book of Nature. Coleridge wrote that "the book of nature [will] become transparent to us when we regard the forms of matter as words . . . an unrolled but yet a glorious fragment" (as cited in Harvey, 2013, p. 99). Given that DNA exists in nature as a tightly coiled spiral in cells, it is perhaps revealing that Coleridge uses the word "unrolled:" DNA, then, is a scroll whose text, once the scroll has been opened, can be created, altered, read, interpreted, copied, and subjected to any other action performed with traditional text.

Additionally, as Harvey explains, the Book of Nature is not static, which is one of the reasons that it is difficult to read and interpret (2013). Only with much time and effort can the Book of Nature accurately be comprehended; in fact, as Harvey contends, because the Book of Nature is dynamic, a complete understanding may not be attainable but should always be aspired to (2013, p. 80). The ability to sequence (i.e., read) DNA represents a remarkable step forward in the ongoing effort to read the Book of Nature more accurately. Further, though, the development of CRISPR and techniques for the synthesis of DNA means that it is now not only possible to read the Book of Nature; it is possible to write and alter it as well. This ability presents numerous challenges because we still do not fully understand the language used in the book. Like the Book of Nature as a whole, DNA is not fixed, given evolutionary and environmental changes as well as genetic mutations. Additionally, only a fraction of the human genome is used to transmit genetic information; the function of the rest of the genome is unknown, as we will see.

Even so, DNA and the genetic code were characterized as a language, and thus as a potential part of the Book of Nature, as early as the 1960s, only a decade after James Watson, Francis Crick, Maurice Wilkins, and Rosalind Franklin discovered the double helix structure of the DNA molecule and postulated its method of copying genetic information. However, DNA's status as a language was limited. Much of the work on "DNA linguistics" from the 1960s to the 1990s focused on structure and information theory (Kay, 2000). To this end, DNA, says Kay, "is not a natural language," given its lack of "phonemic features, semantics, punctuation marks, and intersymbol restrictions" (2000, p. 2). I might quibble here with the necessity of phonemes and also with punctuation marks and argue, on the latter point, that DNA stop codons (discussed in more detail below) function the same way that grammatical periods do. Still, the larger issue is that until now, DNA's identity as a language has been quite stunted. Given the absence of semantics, DNA has not been accorded any level of rhetorical (or narrative) potential, which are functions we ascribe to any traditional spoken or written language. As a result, Condit's reluctance to grant DNA the prestige and power of rhetoric in 1999 is understandable and appropriate. While linguists were intrigued by DNA's role in the transmission of genetic data and its structural characteristics are similar to traditional text in some ways, rhetoricians did not find DNA worthy of much attention given its lack of rhetorical facility. Perhaps, though, to draw on a language-related metaphor, the writing was on the wall. Theorists in disciplines other than rhetoric have, for quite some time, looked for ways for DNA to count as a full-fledged part of the Book of Nature. The development of CRISPR means that DNA will finally get its own chapter in that book. Accordingly, Condit's account of the rhetorical potential of DNA needs to be updated.

In this article I focus on the textual nature of DNA. But the converse—the biological nature of text—also has a long-established tradition. Language, like DNA, has been described as "natural" or "organic" for millennia and thus worthy of scientific study. Even the earliest of texts about rhetoric, such as the *Encomium of Helen*, characterize the use of language as a physiological phenomenon potentially akin to the metabolism of powerful drugs. Coleridge and other Romantics and Transcendentalists spoke of a "science of words" implying that words could be studied scientifically in a manner similar to that of all objects and processes of nature: indeed, language was viewed as "natural" (Harvey, 2013, p. 55, 79). More recently, returning to the medicinal metaphor, Hawhee (2009) sees Burke's pharmaceutical view of language as having arisen at least in part from his work as a drug researcher. Similarly, as both Condit and Hawhee point out, Burke's well-known definition of human beings as "bodies that learn language" portrays the use of language as a biological, physical process, without effacing its cognitive elements and effort, and without uniting the body and text entirely (Burke, 1935, p. 295; Condit, 1999; Hawhee, 2009).

The recent boom in research on cognitive rhetorics and neurorhetorics foregrounds the organic nature of text as well. For example, David Gruber contends that "Neurorhetorics can become an inventional, performative enterprise invested in multiple ontologies of the brain" (2016, p. 241). In other words, neurological activity itself can be seen as textual and rhetorical, and text can have neurological features. Along these lines, drawing on the work of Jeanne Fahnestock, Randy Allen Harris argues for a strong link between rhetorical and cognitive approaches to the study of language, saying "The more we understand the elemental components of [signification], the more we can chart its reliance on the kind of wetware that defines us as human organisms, the better equipped we will be to influence and educate the culture that defines us as social, political, historical, organisms" (2013, p. 7). (Intriguingly, Harris chooses to illustrate his point by looking at Mendelian genetics, which, given its use of letters to identify dominant and recessive genetic traits foreshadowed the idea of letter-signified DNA as a text as well.) In sum, the long tradition of thinking of language in a biological, neurological, scientific manner bolsters the case that nature, the object of scientific study, can also be conceived as discursive. If indeed DNA is a fully rhetorical text, a depiction of DNA's character closer to that of the Book of Nature than to the somewhat more constrained representations of Burke and Condit is in order.

DNA as Rhetoric: Structural Components, Purposes, Audiences, and Memory

If DNA can be considered a rhetorical text, as the Book of Nature trope suggests, it stands to reason that DNA itself contains rhetorical features. This is, in fact, the case. Perhaps tellingly, since the identification of its structure and the mechanisms of its transfer of genetic material in the 1950s and 1960s, DNA has always been described in terms associated with language. Two of the three stages of genetic information transfer are transcription and translation—terms associated with language long before they were appropriated by molecular biology. Additionally, DNA itself is read as a text consisting of the four letters that correspond with the four biochemical bases mentioned above. A genetic sequence, then, is a long series of As, Gs, Ts, and Cs; the entire human genome is 3 billion letters long. (By comparison, the smallest known genome is in a bacterium called *Carsonella ruddii*, which has 159,662 letters, or about .005% of a human genome [Nakabachi, et al., 2006]). In humans, the genetic letters are contained in about 19,000 protein-manufacturing genes that are stored across 23 chromosomes (Chi, 2016). The language of genetics equates words with codons; sentences with genes, operons, exons, and introns; and paragraphs with chromosomes. As currently understood, DNA is a limited language. It contains only 64 codon-words. However, these codon-words are repeated many, many times across an entire genome. The codon-words, each of which is three letters long, refer to one of 20 amino acids that are the building blocks of the proteins that comprise our bodies. Because the human body uses only 20 amino acids, most of the amino acids have more than one codon-word to refer to them. The code is redundant. There are also three codon-words for "stop"—called "stop codons"—that signal the end of a specific genetic sequence.

The sentences of DNA—genes, operons, exons, and introns—differ in length and function, just as those in traditional text. Genes can be short (100 codon-words) sentences or long (close to 1 million codon-words) sentences. Exons and operons are active (i.e., they have a recognized function) gene-sentences that have recognized rhetorical and biological functions. Not all gene-sentences are active, though, nor are their function(s) currently understood. Groups of the latter, unexplained gene-sentences are called introns. Genetic paragraphs—chromosomes—consist of anywhere from 50 to 2000 gene-sentences. Chromosome-paragraphs have two functions. Of the 23 chromosomes found in humans, 22 are autosomes, which describe the body, and one (the X or Y chromosome) is an allosome, which influences gender. I purposefully use the verbs “describe” and “influence” rather than “determine” or some other similarly overstated verb in an effort to clarify the less-than-fully omnipotent role of DNA—“DNA is not destiny,” as the saying goes—and to reinforce the argument that gender, for example, is now understood to be a much more complex and nuanced biological construct than previously thought.

If we were able to only read DNA letters, codon-words, gene-sentences, and chromosome-paragraphs, Condit would be right; DNA text, with its textual but non-sentient replication would not meet the threshold required for rhetoric. CRISPR, though, allows for the intentional targeting and manipulation of DNA quickly and inexpensively.

The CRISPR technique was developed in 2012 by laboratory teams led by Jennifer Doudna in the US and Emmanuelle Charpentier in Europe (Jinek et al., 2012). The technique utilizes a DNA-based defense and immunity system contained in bacteria that is characterized by segments of DNA consisting of short, palindromic base sequences. These bacterial DNA segments fight off invasions by viruses by recognizing and cleaving the invading virus’ DNA. Scientists using CRISPR are able to target and excise a specific section of DNA in any organism, not just viruses, and, if desired, modify and replace the excised section. As Doudna, Charpentier, and their colleagues point out in the paper announcing the technique, CRISPR is “efficient, versatile, and programmable” (Jinek et al., 2012, p. 820)—in other words, rhetorical. DNA targeting and manipulation had been possible before the introduction of CRISPR, starting in the early 1990s, but the processes that were developed then were precipitously time-consuming and costly, and were also unable to target some sections of DNA. They were also error prone. Thus, a link between DNA and rhetoric was still somewhat tenuous given that most people create, revise, manipulate, and use text purposefully, effectively, and with ease. But, partnered with new technology to synthesize DNA,[2] which is essentially equivalent in a rhetorical sense to the invention of text, CRISPR goes a long way toward leveling the playing field.

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[2] In this article I focus on CRISPR “targeting” and “manipulating” DNA rather than on synthesizing or creating it. In general, given economic and time constraints, as well as ethical concerns, synthesized DNA has not yet been used to manufacture the entire genome of complex organisms, although this sort of work is now feasible.

While it is certainly not yet as easy to utilize CRISPR as it is to use a word processor or printer and copier, the technologies are much closer to each other than they used to be. Indeed, Han Yu observes that, “A growing DIYbio [do-it-yourself biology] community is enthusiastically pursuing synthetic biology” (2017, p. 254). “DIY” implies that expensive equipment and large laboratories are now not as necessary as they once were.[3] In terms of rhetoric, then, DNA text and traditional text are getting closer to becoming essentially equal partners.

In addition to sharing the textual structural components of words, sentences, and paragraphs, the transcription phase of DNA information transfer is essentially a copy-and-paste function similar to that used to manipulate text. During transcription, DNA codon-words are copied and pasted to a molecule called messenger RNA (ribonucleic acid) by an enzyme called RNA polymerase. Ultimately, the information contained in the resulting codon-words is used to manufacture all of the different kind of proteins needed in the body. The process is amazingly accurate, especially given the 3 billion letters that comprise the human genome, but mistakes do occur for a variety of reasons. These genetic typos—mutations—can (but do not always) lead to all of the inherited conditions and disorders that we know about. A genetic spelling and grammar check known as a DNA repair mechanism often fixes mutations. However, mutations are in some instances helpful. Indeed, in a major difference with traditional text, where mistakes are typically viewed as in need of correction, genetic mutations can sometimes ultimately prove beneficial if they result in an evolutionary change, usually through natural selection, that helps an organism adapt and survive. As Condit points out, “[Mutations are] not an accidental feature of DNA; without such mutational failures, without the change in identity, DNA could never have evolved to be what it is” (1999, p. 343). This situation could, though, be seen as analogous to that when a speaker, seeing from the (lack of) reaction by the

[3] DIYbio may mark a back-to-the-future moment. Steven Shapin has explored the home as a primary site of scientific research in 17th century England, before science started moving its endeavors to larger, dedicated laboratories that had no connection to private residences (Shapin, 1988). Intriguingly, DIYbio, and trends such as 3-D printers, which are characterized by inexpensive, rapid, and compact instrumentation that can fit into relatively small spaces, could signify a trend toward science and technology returning to people’s homes. Such a progression would, for example, parallel the technological evolution of computers from the enormous mainframes of the 1950s to the even more powerful, handheld smartphones of the present.

audience that her or his prepared remarks are not working as intended, abandons this text in favor of a new, extemporaneous text that stands a better chance of achieving the speaker's rhetorical goals.

Rhetoric assumes a function (or multiple functions) for text. DNA text does have a specific rhetorical purpose: to reproduce itself in order to manufacture specific types and amounts of proteins that form organisms and bodies and perform metabolic functions. Nonetheless, despite its specificity, the purpose of DNA text is not as easy to pin down as one might imagine. In her work on competing narratives of the gene in evolutionary biology, Debra Journet argues that the purpose of DNA differs on the basis of whether one assigns the role of agent to the gene specifically or to the organism as whole. As she writes, "Attributions of agentivity seem essential to the ability to theorize evolutionary processes" (Journet, 2011, p. 218). If the gene is the agent, the purpose of DNA is limited to self-replication. If, on the other hand, the organism is the agent, two purposes are apparent: survival and reproduction. Now that DNA-creating and DNA-manipulating agents other than the gene and the host organism are possible—a human being who uses CRISPR to achieve a genetic goal heretofore impossible for people to realize consciously and deliberately—it is not inconceivable that a multitude of new purposes for DNA text will emerge. Indeed, DNA text may now have as many (or more) purposes as traditional text does. As with traditional text, though, it is important to always keep the agency of CRISPR use and manipulation of DNA text where it belongs: on the person or people using the CRISPR technique. The CRISPR technique itself cannot be allowed to become an agent that is somehow independent of human motivation and control, as Leah Ceccarelli warns (2018). Maintaining a focus on people helps us to remember that purposes for DNA text, just as for traditional text, can now because of CRISPR be helpful, benign, destructive, or any combination of these, depending on audience(s) and context(s). We must also keep in mind that institutions can co-opt people, including scientists, into their own institutional purposes and ends. So far, the most-discussed purposes, some of which are beneficial and others alarming, for human DNA creation and manipulation have been medical, eugenic, agricultural, and informational (i.e., data storage). But now any purpose associated with traditional text should also be thought of in terms of DNA text. Will, for example, DNA text someday replace a person's signature or be used in some way in a legally binding contract or a résumé or c.v.? Could manipulated DNA be akin to forgery or libel in certain contexts?

Will a person be able to copyright their DNA? This right, for example, might plausibly have given Henrietta Lacks, the mid-20th century African-American woman who died from cervical cancer and whose cancer cells, without her knowledge or consent, were the source of the HeLa cell line that has been used in medical research ever since her death in 1951, a great deal more authority over (and potential compensation for) how her DNA was used.[4]

It is also true that rhetorical texts have audiences as well as authors. In "The Materiality of Coding," Condit limits the idea of an audience for DNA in light of her argument that DNA is not completely rhetorical. She states, "Even in a multicelled organism, in the most fundamental conditions, there is only one audience for the communicative processes of the lifecode, and that is the organism itself (and its offspring, which are other selves to the extent that they share the code)" (1999, p. 346). Because changes in DNA occur during the process of evolution, though, Condit addresses the possibility of multiple purposes and audiences. If genetic changes did not occur, evolution would not exist. The fact that evolution does in fact occur means that some purpose, and hence some audience, is in play (Condit, 1999). In 1999, when Condit's chapter was published, evolutionary change in humans (though not, say, in tomatoes) was still exclusively under the control of nature. The arrival of CRISPR and synthetic DNA has, however, changed this dynamic. As such, audiences for DNA texts are no longer the province of nature only. Now that DNA text can be not only read but invented, anyone who is interested in (and/or alarmed by) the idea that DNA can be written to achieve a specific purpose is a potential audience for this text and as an audience has the ability to influence how the text is written and manipulated.

Another significant difference between traditional text and DNA text involves stakeholders, especially the idea that stakeholders potentially far outnumber audience members and may in fact be impacted far more radically. When the topic of designer babies comes up, we typically think of changes to DNA as affecting only that one person. These sorts of changes are indeed possible if genetic changes are made to what are called somatic cells, which are cells that eventually become skin, bones, blood, muscles, connective tissue, and internal organs. However, genetic changes to germ cells, which are cells that eventually become part of a person's

[4] In 2013, Lacks' descendants reached an agreement with the U.S. National Institutes of Health in which they gained a measure of control over the use of the HeLa genetic sequence.

reproductive system,[5] not only affect the person for whom the genetic change was performed, but all of her or his descendants as well.[6] The most important stakeholders for DNA text, then, haven't even been born yet. Changes to the sex-related sentence-chromosomes will be manifested not only in the embryo undergoing treatment but also in all future generations. Thus, the audiences—and stakeholders—of DNA text are exponentially larger than even the most famous traditional texts ever written. Indeed, for changes made to the sex-related chromosomes, the audiences and stakeholders are all of future humankind.

A rhetoric of DNA that results from the development of synthetic DNA techniques and CRISPR points most obviously to the classical canons of invention, arrangement, and even style, but memory is also in play. Not only is DNA the substance responsible for the transfer of hereditary traits; it also is viewed as a data storage method with immense potential. To this end, as proof of concept, a team of scientists has used CRISPR to add photographs and a simple animated GIF video of a galloping horse to strands of *E. coli* DNA (Shipman, et al., 2017). The data were not only stored, but also copied as the bacteria reproduced, thus adding redundancy, though with some loss of accuracy. This use of CRISPR will allow cells to record interactions they have with other cells as well as with invaders such as viruses. Thus it may be possible to construct an archive of cellular responses with respect to potential illness-inducing organisms (Shipman, et al., 2017). This research demonstrates that the full suite of memory and storage techniques currently available for traditional text is now equally applicable to DNA text. In this way, DNA text may eventually become a topic of inquiry for archivists, information managers, information architects, and historians in addition to being an object of study for rhetoricians and other textual scholars.

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[5] Germ cells should not be confused with the germs that are disease-causing microorganisms. Like wheat germ or any other kind of cereal germ, germ cells are reproductive components.

[6] This idea does not discount the fact that evolution sometimes seems to produce random changes, such as silent genetic mutations that seemingly serve no apparent purpose, and genetic drift, which refers to seemingly arbitrary changes between generations in the frequency of a particular gene in a certain population, usually a small one.

Language-Related Implications of Considering DNA as Text

A number of language-related implications arise from characterizing DNA as rhetoric. Let's first consider a recent, common characterization of DNA—that of DNA as code (Condit, 1999). One of the most successful popular science accounts of DNA was David Kevles and Leroy Hood's 1992 edited collection entitled *The Code of Codes: Scientific and Social Issues in the Human Genome Project*. Coding implies a linear and controllable process. But CRISPR has demonstrated that such control is, at present, far beyond our capability. By 2011, then, nineteen years after the publication of *The Code of Codes*, another popular book about DNA, written by geneticist Francis Collins, the Director of the National Institutes of Health and one of the scientists responsible for sequencing human DNA, was published. The title of this book doesn't mention the word "code;" instead, the book is called is *The Language of Life: DNA and the Revolution in Personalized Medicine*. DNA has become a language rather than a code, a change that represents a noteworthy shift from thinking of DNA as rigid and linear to a more complicated conception of DNA as malleable and recursive.

This characterization is not without controversy. As Han Yu points out, the sequencing of the human genome

> has served to re-mystify the code enigma that earlier work helped to peel away … [T]he findings of the Human Genome Project and subsequent studies led researchers to conclude that despite obtaining whole-genome sequences, we know very little about what those sequences actually mean (2017, p. 153).

Tropological characterizations of DNA are indeed contested, but describing it as a language is becoming more common. Even so, DNA is a language we are only beginning to understand. That's why O'Keefe et al. have argued that editing is a not a good metaphor for making changes to DNA (2015). While the idea of making changes is an accurate parallel, the editing metaphor also implies that we know what we're doing—that we're correcting misspellings and comma splices that we can easily recognize or, on the substantive editing level, adding or deleting content as appropriate. But in many cases in DNA text, we don't even know what the correct spellings are or how the grammar works, much less most of the content of the language. Our knowledge of the language is much more rudimentary. We only know the alphabet, with its four letters A, G, T, and C, and a few words. A huge majority of DNA—nearly 97%—consists of letters that do not ultimately produce the amino acids that are the building blocks for proteins. Scientists have a basic awareness that these large DNA segments somehow help control genetic and biochemical functions, but this awareness is in its earliest stages. In these non-coding DNA segments, we can see the sequence of letters, but we can only make the most elementary, if educated, guesses as to its meaning. Accordingly, we have far less control over DNA text than over traditional text, and the idea that we can "edit," or even more problematically, "proofread" DNA text in the same way that we correct a typo or run-on sentence or add a clarifying explanation, as we do with traditional text, is, at least at present, fundamentally flawed, contrary to what Chen et al. assert or imply (2018, p. 194a). The editing metaphor also implies that we have authors or other experts in the field with whom we can consult in an effort to figure out what's going on in a text and the best way to express it. With DNA, however, we don't have the luxury of an author or expert to talk to. Similarly, translation is a problematic metaphor. Unlike, say, Mandarin Chinese, we don't have native speakers of DNA to talk to. There is no authority, then, with whom we can consult to discuss the accuracy of our interpretation. Perhaps we should think of DNA text something more akin to Celtic runes or some ancient language with no known speakers remaining but that can be deciphered. But even that analogy is far from perfect. It still involves the action of inscribing our own knowledge and context into an unknown language, a tactic that invariably leads to imprecise or even flat-out wrong translations, with potentially dire consequences.

Still, even though we possess only a rudimentary knowledge of DNA text, its potential is so enormous that we cannot wait to begin thinking of its textuality as rhetorical. Increased understanding and precision with respect to DNA is likely to be forthcoming, and it is vital that we stand ready with the requisite inventional and critical rhetorical tools, and prepare to create new ones, in order to engage this new form of text thoughtfully and ethically.

Including rhetoric in DNA text's repertoire of language-related functionality has the added benefit of resisting the trend toward the coronation of code "as the *lingua franca* of nature" (Hayles, 2005, p. 55). The increasingly hyped importance of technology—for example, in exhortations to send our kids to coding camp—leads to the notion that traditional "[s]peech and writing ... appear as evolutionary stepping stones necessary to ratchet up *Homo sapiens* to the point where humans can understand the computational nature of reality" (Hayles, 2005, p. 55). At the moment, human interaction is still largely an analog endeavor. Accordingly, codes should, indeed must, exist in partnership with language. N. Katherine Hayles notes that programming languages such as C++ are becoming more like languages than traditional codes (2005). As a result, the line between language and code is becoming increasingly indistinct. Thinking of DNA as a rhetorical text will blur this line even further.

A second, philosophically inflected, language-related implication of considering DNA as text is the idea that a characterization as text refutes the common perception of DNA as deterministic. A code is often thought of as deterministic; language is less so. Thus DNA may be perceived as more fluid and nuanced if it is understood as a text. A December 2015 international CRISPR summit summary captures current areas of indeterminacy in CRISPR research. They include the following: CRISPR may change DNA at locations other than the target; it may alter DNA in some cells but not others; and it may provoke unintended immune responses (Olson et al., 2015). These findings have since been confirmed and expanded upon, as is the suspicion that the use of CRISPR can cause unintended mutations (Schaefer et al., 2017). It can also cause inadvertent DNA rearrangements and deletions (Kosicki et al., 2018) and induce the onset of cancer (Haapaniemi et al., 2018). This work also demonstrates that some cells are able to resist attempts to use CRISPR to alter their DNA. Like traditional text, then, DNA text can be messy and unpredictable. DNA text has a life of its own beyond the intentions of its creators and users—a characteristic of text that rhetoricians are well equipped to contend with.

A third implication of characterizing DNA as text is the idea that we need to think about intellectual property associated with DNA in new ways. Copyrights and trademarks, which are forms of intellectual property typically associated with text, may become equal in importance to patents, which are more common in the sciences, especially the sciences of DNA. For example, ownership of CRISPR was the subject of litigation between Doudna and Charpentier on one side and, on the other, Feng Zhang, a scientist at The Broad Institute operated jointly by Harvard and the Massachusetts Institute of Technology. The crux of the dispute was that Doudna and Charpentier's initial patent for CRISPR focused on the technique's use in prokaryotic organisms (i.e., those without a nucleus or other membrane-bound organelles). Zhang's later patent demonstrated the use of CRISPR in eukaryotic organisms (i.e., those with a nucleus and membrane-bound organelles). Doudna and Charpentier challenged Zhang's patent but lost the legal fight on the grounds that, even though the use of CRISPR in eukaryotic cells is a logical extension of its use in prokaryotic cells, they had not yet perfected the process to use CRISPR in the more complex cells. One wonders if a different outcome would have been reached had DNA been thought of by the court and its expert witnesses more as text and thus as more an issue of copyright. A short and/or simple text is just as much a representation, expression, or embodiment of language as is a long and/or complicated text. Both are eligible for the same kind of copyright protection even though the process for producing a long, perhaps more complicated text generally requires more effort. The ruling against Doudna and Charpentier seems unnecessarily deterministic in the sense that the distinction between prokaryotic and eukaryotic cells would probably be viewed as materially valid, but ultimately inconsequential in the more holistic and dynamic world of rhetoric. Additionally, the ruling exhibits a linear view of DNA. Although there are only four letters in the language of DNA, they combine in enormously complex ways. Like any text, DNA text cannot always be read linearly, as parts of DNA words or sentences can appear in multiple, disparate areas of the genome.

A fourth implication of considering DNA as text arises from thinking about the idea that technology influences both the perceptions and practices of language use. Like language, science is inevitably linked to the particular technology used to advance its goals. DNA text is a much different kind of text than those associated with digital and print media technologies. It is tempting to think of DNA text as digitally compatible given the huge amounts of data associated with this kind of text and the technical nature of its content. However, as Hayles explains, other bodily (nondigital) processes contribute to the formation of the text and message:

> DNA is often understood to operate as a digital code, in the sense that it is discrete rather than continuous. With the sequencing of the human genome, however, it has become clear that sequence is only part of the story, perhaps even the less important part. Protein folding, an analog process that makes use of continuous transformation in form, is essential to understanding how the genome actually functions. The *combination* of the two processes, the digitality of DNA sequences and the analog process of protein folding, gives the

> gene its remarkable power of information storage and transmission (2005, p. 29).

Although it shares some features with other kinds of text, DNA text is unique because it lives in a new textual medium, the body, which influences the text in ways completely different from effects associated with traditional print and digital environments. DNA text may also introduce a new way of thinking about genre—"biogenre," perhaps.

A fifth implication of considering DNA as text is that, in addition to existing as rhetoric, DNA can also exist as narrative and even as aesthetic, an idea that the Book of Nature trope authorizes. Hayles maintains that computers and programming languages should now be understood as expressive, artistic media (2005). DNA should be viewed similarly. As both rhetoric and narrative, DNA text can be read usefully through any and all of the lenses used for traditional text: feminist/gendered, racial/ethnic, socioeconomic, deconstruction, reader-response, stasis theory, historical, psychoanalytical, and environmental, among others. In his 1993 edited collection *Understanding Scientific Prose*, Jack Selzer chose a scientific text from evolutionary biology, Stephen Jay Gould and Richard Lewontin's "The Spandrels of San Marco and the Panglossian Paradigm: A Critique of the Adaptionist Programme," and asked each of the contributors to his book to interpret the text through a different theoretical lens. As Selzer explained, his purpose for the book was to help people better understand scientific rhetoric by "introducing and demonstrating appropriate ways of performing rhetorical analyses—ways that are likely to be especially productive in the case of scientific discourse" (1993, p. 6). This same project should eventually be applied to DNA text. Once this kind of text is better understood, it will be fascinating to see how DNA is perceived and interpreted in all of these different ways.

Conclusions

A 2017 genetic study of the indigenous Tsimané tribe in the Bolivian Amazon found that elderly tribe members who had high levels of parasites in their bodies—a condition that often leads to cognitive impairment—were in many cases able to retain cognitive function if they carried the genetic E4 allele (i.e., mutation) (Trumble et al., 2017). This finding was surprising because in countries more developed than Bolivia, the presence of the E4 allele, rather than positively influencing cognitive function, is instead a strong predictor of Alzheimer's disease. If DNA is considered a code or a set of technical data, it is difficult to make sense of this seemingly striking contradiction. However, if the E4 allele—and DNA more generally—is considered a rhetorical text, the contradiction is less apparent and problematic because we are far more used to, and comfortable with, ambiguity and the crucial importance of context and environment when it comes to matters of language. We understand that different texts mean different things to different people in different places. It turns out that DNA is just like rhetorical text in this regard. Like text, the E4 allele must be interpreted and contextualized to reach a more complex understanding of it.

Thinking of DNA as a language complicates it, but such a perception makes DNA more accessible because people are more at ease with language than with code or data. Indeed, despite being a "disruptive" technology, as she admits, Jennifer Doudna sees the ease and low cost of CRISPR as an important part of the "democratization" of gene targeting and manipulation (Rose & Doudna, 2018). Given that DIY biology is real and that CRISPR may be able to be used by non-scientists outside of laboratory settings because of its speed and accessibility, genetic literacy is fast becoming one of the most important literacies for people to achieve (Meyer, 2018). The state of genetic literacy is generally mediocre at best and is influenced by identity other motivating factors (Condit, 2010). Popularizing the idea that DNA is a text may help to improve the comprehension of important genetic information and processes, knowledge that is important in our age of increased genetic testing and counseling as well as the threat of genetic surveillance.

A key element of a robust rhetoric of DNA will be a balance between a well-informed understanding of DNA text and a concurrent critical stance toward it. It is important that DNA text not be used unreflectively as a legitimizing rhetoric, as much of scientific rhetoric too often is. Gruber has noticed this trend in the discourses of the neurosciences. He writes, "Incorporating a brain-[science]-finding by making it fit into a[nother] field's existing discourses and practices—as opposed to subjecting a finding to scrutiny—seems likely" (Gruber, 2016, p. 240). Rhetoricians of science must demonstrate by example how to engage DNA text critically and constructively.

Although DNA with its four-letter alphabet, codon-words, gene-sentences, and chromosome-paragraphs is a text that is only beginning to be understood, its power as a rhetoric, unleashed by CRISPR, is already being exploited and experienced, for better and for worse. Rhetorical concepts such as purpose, audience and stakeholders, invention, arrangement, and style, as well as knowledge of the means of technological production of DNA text, are now plausible and indeed evident. Even though our understanding of DNA text is limited, it is already, unmistakably among the most potent kinds of text that can affect identity and health. In *A Crack in Creation: Gene Editing and the Unthinkable Power to Control Evolution*, a personal account of her work on CRISPR, Doudna and her co-author Samuel Sternberg seem keenly aware of the technique's seismic implications, calling the "conscious, intentional system of human-directed evolution" brought about by CRISPR a "colossal responsibility" (2017, p. 244). For this reason, Doudna strongly and publicly supports research on and discussion of the ethical, political, and social implications of CRISPR (Doudna & Sternberg, 2017). Rhetoricians need to be a part of these efforts.

A rhetoric of DNA should not and cannot only be textual in the traditional sense. Given that we live in a culture in which alphabetic texts are sometimes less rhetorically effective than visual texts, a vigorous visual rhetoric of DNA is crucial to the development of a more widespread genetic literacy (Yu, 2017). Rhetoricians of science should also consider effective uses of pathos appeals with DNA text given that logos and ethos appeals at times prove to be unsuccessful with some audiences (Condit, 2010). Today's short attention spans should lead rhetoricians to craft messages that are brief and to the point. Using narrative, comedy, and other forms of indirect rhetoric may sometimes work better than a straightforward approach.

Characterizing DNA as a rhetorical text that can make an argument and tell a story, as theoretical constructs such as the Book of Nature trope allow us to do, enables rhetoricians and other scholars of language to bring to bear the full weight of text-focused theory and empirical research in an effort to better understand DNA's creation, replication, manipulation, and potentially momentous, far-reaching, long-lasting implications. Textual awareness of DNA as text, which as I have been arguing can no longer be understood as merely metaphorical, is vital because all of the power and ethical issues associated with traditional text are now the province of DNA text as well. Indeed, we might speak of DNA text as having "biopower" in Foucault's sense if we keep in mind (as Foucault himself did not always do) that it is always human beings who wield this power and are responsible for it (Kay, 2000, p. 19). Given the material and long-term consequences of the creation and manipulation of DNA text, the paradigm shift that CRISPR represents means that gender, race, and class are now more important and contested than ever. It is all too easy to imagine dominant DNA discourses, just as there are dominant discourses of other sorts. At times seemingly intractable gendered, racial, and class-based misperceptions and divisions that exist with traditional text are now at risk of being exacerbated and reified with DNA text. Genetic profiling and sorting, with the inevitable consequences that will be suffered by those deemed to have inferior DNA, are right around the corner, as films such as *Gattaca* (DeVito, et al., 1997) have aptly anticipated. CRISPR will help those with wealth and power, and perhaps even some without such advantages if they have robust health insurance or live in a country that guarantees healthcare for all. The Internet and digital texts have been unable to dislodge the hold that hate speech has on our culture, and perhaps it was unrealistic to expect that they would do so in the first place. So too should the textualization of DNA not be burdened with naïve hopes. However, if rhetoricians of science—perhaps "biorhetoricians" working in tandem with "rhetorical geneticists" in the future?—become actively involved in the study and policy-related work of DNA, treating it as the more fully rhetorical text that it is becoming, the promise rather than the peril of DNA text stands a much better chance of being realized.

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