Ancient Genetics to Ancient Genomics:

Celebrity and Credibility in Data-Driven Practice

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Introduction

The search for DNA from ancient and extinct organisms – a practice now known worldwide as "Ancient DNA Research" – surfaced from the interface of paleontology, archeology, and molecular biology in the 1980s, then evolved from an emergent into a more established scientific and technological practice today. Throughout the decades, this novel approach to the study of fossils has grown under intense press and public interest, particularly as it coincided with and was catalyzed into the media spotlight by the book and movie *Jurassic Park* in the 1990s. Ancient DNA continues to capture professional and popular attention as researchers have recovered genetic material from extinct mammoths to early humans and Neanderthals in an attempt to refine or even rewrite our understanding of evolutionary history. This practice also captures public curiosity because of speculation – inspired by media reports as well as scientific research – that DNA may one day be used to bring extinct species back to life.

Broadly, ancient DNA research is the practice of extracting, sequencing, and analyzing degraded or damaged DNA from dead organisms that are hundreds to thousands of years old. Ancient DNA has been recovered from organisms such as plants, animals, humans, and bacteria, and can be preserved in skins, tissues, and even bone if the bone is not a fully mineralized fossil.[1] However, it is important to note that the term "ancient" does not necessarily relate to the age of the DNA but to the characteristic damage patterns that occur as DNA breaks down after an organism has died. Given the degraded nature of this genetic material, research into DNA from ancient and extinct species requires specialist skills and technologies. Many researchers are interested in adapting state-of-the-art molecular biological techniques and high-throughput sequencing technologies in order to optimize the recovery of ancient DNA. They are also interested in using this DNA for the primary purpose of studying the evolutionary history of extinct and extant organisms as well as testing hypotheses about evolution, such as the drivers of patterns of genetic variation, regions of the genome under selection, and the migrations of past populations. At the same time, however, the ability to recover DNA from fossils has been closely connected to the idea of using DNA to

[1] Specifically, a fully mineralized fossil is unlikely to preserve DNA, whereas a subfossil, a partially mineralized part of an organism, may retain remains of its cellular or molecular components. Specifically, an organism's status as a fossil or subfossil, or whether it exists as a piece of skin or tissue, matters when considering whether cellular or molecular components may be preserved. Regardless, I use the terms "ancient DNA research," "the search for DNA from ancient and extinct organisms," or the "search for DNA from fossils" interchangeably throughout this paper to refer to general study of degraded and damaged DNA from a variety of sources. Elsbeth Bösl has also written on the history of ancient DNA research via a recently published article, "Zur Wissenschaftsgeschichte der aDNA-Forschung" (March 2017), and a recently published book, *Doing Ancient DNA: Zur Wissenschaftsgeschichte Der Adna-Forschung* (August 2017), in German. See Bösl (2017a) and (2017b).

resurrect extinct species.[2] Since the 1980s, speculation about resurrection has followed the field closely, influencing the development of this practice over a prolonged period of time.

Drawing on historical and archival material, interviews with scientists, and philosophical literature, this paper presents the search for DNA from fossils, throughout its disciplinary development from the 1980s to today, as a data-driven and celebrity-driven practice. This paper proceeds in three parts. First, I deliver a condensed history of ancient DNA research from the 1980s to today with attention to the role that technology as well as consistent press and public interest played in its growth from a curious idea into a credible practice within evolutionary biology. Second, I introduce interviewees' memories of their history and analyze their perspectives on the historical and philosophical development of ancient DNA activity as an extended episode of boundary-work. In attempts to make sense of their history as a science in the spotlight, interviewees try to draw a line between their past and present in order to portray the practice as a more question-driven, and therefore more mature, area of research today. Finally, I discuss the role of celebrity and credibility in the data-driven practice of ancient DNA research.

Methods and Definitions

In analyzing the methodologies of ancient DNA researchers over a thirty-year-period, it is necessary to address my own methods that were used in the writing of this history. Specifically, I approached this project as a historian of science with a focus on oral history methods which included qualitative interviews with fifty-five scientists, as well as doctoral and postdoctoral researchers, involved in ancient DNA research. The interview method was semi-structured in style, on average two-hours in length, and resulted in partial-transcriptions for analysis. The interviewees represent researchers from disparate disciplines within evolutionary biology and can be characterized within the following categories: paleontology, archeology, anthropology, botany, epidemiology, evolutionary genetics, population genetics, molecular biology, microbiology, and computational biology. These interviewees work within the following countries: United States, Canada, England, Ireland, Australia, Germany, Denmark, Sweden, Norway, France, Spain, and Israel. Efforts were made to interview researchers who represent different

[2] Research dedicated to the idea of bringing back extinct species is known as "de-extinction" and refers to the process of recreating an organism that is a member of, or resembles a member of, an extinct species through back-breeding, cloning, genetic engineering, or reverse genetic engineering. I use the terms "de-extinction," "resurrection," and the idea of "bringing back extinct organisms" interchangeably in this paper. See Shapiro (2015) and Wray (2017).

scientific, epistemic, and generational views regarding the proper practice of ancient DNA research. These interviewees were not selected at random but are a sample of the population of researchers in North America, Europe, and Australia.[3]

The goals of the interview transcriptions were qualitative and thematic.[4] Throughout the data collection, transcription, and analysis process, I generated a list of themes regarding the practice's development. These themes were informed by professional and popular literature on the search for DNA from fossils as well as information from interviewees. My analyses and arguments in this paper reflect my effort to listen for reoccurring themes in the retelling of the history, as well as conflicting viewpoints that suggest there is more than one story to tell. I have tried to represent the community's various viewpoints, including their disagreements, while listening for overarching themes about the practice's history that are shared amongst scientists across space and time. The one common theme running through their accounts, in addition to contamination concerns as related to ancient DNA authenticity, is the role of the media. Interviewees all agree on the role of the media as a direct or indirect influence on the development of ancient DNA research within evolutionary biology. Consequently, this paper focuses on interviewees' perceptions of their history as being both a data-driven and celebrity-driven practice, and it discusses the implications that this has for understanding the epistemology of science.[5]

Before proceeding further, I want to clarify what I might mean by a "data-driven" approach. In this paper,

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[3] Interviewees were selected via the professional and popular literature (scientific publications to media reports and reviews) on the topics of ancient DNA activity and de-extinction. Interviewees were also selected at "Ancient DNA: the first three decades," a commemorative conference hosted by the Royal Society in London in November 2013 to celebrate its thirty-year history. Additionally, interviewees were identified by "snowball sampling," the process by which potential interviewees are chosen based on recommendations made by previous interviewees (Atkinson and Flint 2001). Overall, many interviewees were high-profile researchers in the field. However, efforts were taken to reach out to scientists who were less well-known or who have been or have felt marginalized throughout the history of their science and even today. This methodology (the interview process and permissions) was approved by the Ethics Committee in the Department of Science and Technology Studies at University College London. Interviewees gave consent for the author to use their interviews and information in the form of anonymized quotations. For additional information on methodology, see Jones (2017).

[4] This does not mean that a quantitative approach would not be useful or will not be done in the future. However, for the purposes of this research, the primary objective was to conduct and analyze extensive qualitative interviews with a wide-range of scientists in the field from a variety of disciplinary backgrounds and national contexts using oral history methods.

[5] The fact that I am writing about the role of celebrity in science makes me a participant in the making of celebrity too. First, in telling a narrative of ancient DNA research as a science under the influence of celebrity, I am reinforcing the spotlight which will further affect the researchers working in or around this practice. Second, in writing about celebrity, I am acknowledging that my research is a product of it and that it will be affected by it. Sure enough, there will be consequences from situating my work within a celebrity science context, and I appreciate the need to be reflexive regarding this issue.

there are two ways to think about data-driven research, from a philosophical and a scientific point-of-view. First, philosophers, especially those interested in the contemporary biological and biomedical sciences, have started to study the nature of data-driven science (discussed in detail in part three) (Leonelli 2012). In drawing on a number of case studies across the sciences from natural history and system biology to genomics more broadly, these scholars produced the first philosophical and historical treatment of contemporary data-driven sciences. In the process, however, they found that this phenomenon of data-driven inquiry was in fact difficult to define. In her introduction to the topic, Sabina Leonelli conceded that a "general characterization of data-driven research is hard to achieve, given the wide range of activities and epistemic goals currently subsumed under this heading." Nonetheless, she pinpointed "two key features" that are "often highlighted as pillars of this approach." According to Leonelli, these two features included "the intuition that induction from existing data is being vindicated as a crucial form of scientific inference, which can guide and inform experimental research" and "the central role of machines, and thus of automated reasoning, in extracting meaningful patterns from data" (Leonelli 2012, 1). In my history of ancient DNA research, I view researchers to be data-driven in terms of one) the samples, two) the technology, and three) the molecular information (DNA) that can be recovered from accessible samples using the existing technologies. I interpret these elements as data and I understand scientists' desire to pursue these features as either A) objects or as B) objects of information as an act of being data-driven.

Second, it is necessary to mention that in my history of ancient DNA research, the scientists themselves also have their own view of data-driven research and how it relates to scientific practice (discussed in detail in part two). Indeed, in my interviews with scientists, most view data-driven approaches (in terms of the samples, technology, and information that can be obtained from both) as being in opposition to hypothesis-driven approaches. Both philosophical and scientific discussions of this have been inspired by the rise of big data across the scientific disciplines. This phenomenon has caused scholars and scientists alike to examine the novelty of data-driven inquiry as a new mode of scientific inquiry and to reevaluate the place and preference for hypothesis-driven or question-driven methodologies in scientific practice (Leonelli 2012; Leonelli 2016). In this paper, my goal is to try to bring practitioners' perceptions of data-driven research, in the case of the history of ancient DNA research, into conversation with philosophers' perspectives on this same subject.

Additionally, the idea of being "celebrity-driven" – like that of being "data-driven" – is also difficult to define. In the celebrity studies literature, there is no clear consensus on what constitutes celebrity. Sure enough, the definitions of both celebrity and celebrity culture are up for debate (Rojek 2001; Evans and Hesmondhalgh 2005; G. Turner 2004). Nonetheless, I draw on Graeme Turner's definition of celebrity which he takes to be both a process and a product. Turner, for example, considered celebrity to be "*a genre of representation"* and *"a commodity traded by the promotions, publicity and media industries that produce these representations and their effects"* (2004, 9). Under this definition and according to my case study, celebrity might be understood as having a sort of appeal to or authority over the public. This appeal or authority is attained through fame and the glamorous, even notorious, status that comes with it and is then repeatedly reinforced by media interest in it. Crucially, I am not referring to celebrity on the individual level by pointing out a *single scientist*.[6] Rather, I am referring to celebrity on the group level and the celebrity that exists around a *subject of science* (content of research) with attention to how it affects the overall group of scientists and the production of knowledge.[7] In this case, it is the celebrity that surrounds the practice of

[6] Scholars have discussed the role of celebrity in science at the individual level. In the 1970s, science communication scholar Rae Goodell profiled a series of scientists from the anthropologist Margaret Mead and biologist Paul Ehrlich to the chemist Linus Pauling and astronomer Carl Sagan. Goodell called these scientists "visible scientists" (Goodell 1977). According to Goodell, these visible scientists shared personal and professional characteristics (media-oriented characteristics) that helped them attain press and public visibility. They used their visibility as a platform from which to speak to the public not just about science but also about science policy. More recently, Declan Fahy introduced the notion of "celebrity scientists" (Fahy 2015). For Fahy, this is a new type of scientist that has emerged in light of the rise of the new celebrity culture. These celebrity scientists, like the late cosmologist Stephen Hawking and late paleontologist Stephen Jay Gould, were credentialed experts in their professional sphere but had also attained fame, fortune, and influence in the public realm. As celebrity scientists, they used the media as a public platform to popularize science then influence public attitudes towards science. According to Fahy, however, stardom's influence cuts both ways. In fact, their stardom affords them influence outside *and* within science. In other words, stardom filters back into science, affecting the process of science.

[7] In my work, I am talking about the role of celebrity on the group level and the importance of understanding how a subject of science can be made into and marketed as a commodity. Thinking of celebrity on the group level requires us to ask and answer the following questions: How does the mass media represent a subject of science to the public? How do researchers respond to the media spotlight? What are the effects of this attention on the science itself? In the case of the history of ancient DNA research, my studies explored how celebrity works in relation to a subject of science, namely the practice of extracting DNA from fossils for studying evolutionary history and even potentially using that DNA to bring extinct species, such as dinosaurs, back to life.

recovering DNA from fossils, its application to questions in evolutionary biology, and even the idea of potentially using it to bring back extinct creatures as embodied in the book and movie *Jurassic Park*.[8]

Here, I want to note the difference between being "publicity-driven" and "celebrity-driven," a distinction which is also far from clear. According to the Oxford English Dictionary, "publicity" is defined as "[n]otice or attention given to someone or something by the media," whereas "celebrity" is defined as the "[t]he state of being well known."[9] Although most science and technology enjoys publicity from time to time via media headlines, article features, or special interviews, not all science falls subject to celebrity. In other words, all celebrity involves publicity, but not all publicity leads to celebrity. Indeed, celebrity is much more than intermittent promotion. In the case of this history, celebrity is both a process and a product of consistent science-media interactions. It is the outcome of prolonged publicity that is actively pursued and produced by both scientists and members of the media. Here, science-media interactions are more than episodic and individualistic. Ancient DNA was shaped by celebrity – specifically celebrity attained through the worldwide fame of the *Jurassic Park* franchise – over a prolonged period of time.

In this paper, I do not present hard-and-fast definitions of what it means to be data-driven or celebrity-driven. However, I do suggest some possibilities for what these terms might mean and how they might be understood in relation to the practice of science and philosophy of science today, particularly in regards to scientific or philosophical perceptions of hypothesis-driven research. Specifically, this history of the search for DNA from fossils will demonstrate that the traditional distinctions or debates between data-driven and hypothesis-driven research are not always sufficient for understanding the process and practice of science. In light of this, I will argue that my study of ancient DNA activity demonstrates the degree to which a both a data-driven and a celebrity-driven

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[8] My doctoral research argued that the history of ancient DNA research can be characterized as a history of celebrity science. The term "celebrity science" is an original concept and initial product of my historical and archival research as well as my interviews with scientists. In my doctoral thesis, I argued that a celebrity science is a subject of science that evolves within a shared conceptual space of professional, press, and public expectations that contribute to the shaping of the science. Here, the mass media are critical in the making of a celebrity science because they seek the science as well as its scientists for its news values and potential to attract public attention. But press and public interest are not enough. Researchers have to participate in the process, too. The mass media are so influential that researchers respond, positively or negatively, to the attention and even reinvent the reputation of their technoscience accordingly. Ultimately, a celebrity science is the outcome of prolonged publicity advanced by a relationship that is actively pursued then produced by both scientists and members of the media. It is an active process and a dialectical process. Ancient DNA is a case study of celebrity science but is by no means an exclusive example of it. Broadly, my doctoral thesis suggests this concept as a model for other scholars interested in studying other sciences in the media spotlight. For additional information on this concept, see Jones (2017).
[9] For a definition of publicity, see https://en.oxforddictionaries.com/definition/publicity. For a definition of celebrity, see https://en.oxforddictionaries.com/definition/celebrity.

approach can influence scientific practice, and I suggest that this has important implications for philosophical questions regarding the epistemology of science.

Ancient DNA as a science in the spotlight

In the late 1970s and early 1980s, the search for DNA from fossils arose independently among different people in different places (Jones 2018). The individuals involved in the emergence of this practice ranged from futurists and enthusiasts to scientists and the popular press. In their own way and through their own means, they contributed to ancient DNA's early intellectual history by advocating for the exploration of the theoretical preservation and potential extraction of DNA from ancient organisms, as well as the hypothetical resurrection of extinct species from DNA recovered from this fossil material. A number of these individuals specifically speculated about the recovery of DNA from insects trapped in ancient amber and even proposed the possibility of discovering dinosaur DNA (Tkach 1983; Pellegrino 1985). Indeed, since the start, the idea of extracting DNA from fossils was closely connected to the idea of bringing back extinct species such as dinosaurs. The connection between these ideas played out in both professional and public contexts well before the release of the now famous book (1990) and movie (1993) *Jurassic Park* (Tkach 1983; Benton 1985). Overall, these individuals, and the ways in which they played a part in the birth of this new line of research, demonstrates that the origins of scientific questions, disciplines, or techniques sometimes emerge from ideas or individuals outside the conventional confinements of the research environment.

However, the reception of these unconventional ideas depended on actual evidence for the feasibility of DNA both existing in and being able to be extracted from fossils in the first place. In other words, it was fundamental that scientists be able to turn their speculation into experiments with evidence in order for their ideas to be further considered then tested. In 1984, a team of researchers at the University of California, Berkeley, including Allan Wilson and Russell Higuchi, successfully extracted, sequenced, and analyzed DNA from the remains of *Equus quagga*, a zebra-like relative of the horse that was declared extinct in the late 1800s (Higuchi et al., 1984). While some researchers at the time recognized the quagga study as a conceptual, technical, and empirical breakthrough, they also saw it in this light because it was published in a well-read and well-respected journal such as *Nature*. Publication in *Nature* sent a statement of authority and legitimacy to the scientific community and also to the public. The search for DNA from fossils, once a fantastical idea, appeared to be transforming into an exciting research endeavor with the potential to travel back in time to study evolution in action (Jeffreys 1984). Yet increasing evidence for the preservation of DNA from fossils led to increasing speculation about resurrecting long-lost creatures (Clifton 1984). This interplay between the scientific and the speculative would continue to influence ancient DNA's growth within evolutionary biology (Jones 2018).

Indeed, philosophers have also analyzed the role of speculation in science. According to Adrian Currie and Kim Sterelny, for example, "speculation" can be a "vice" when it is "idle" or "pointless." In other words, speculation can be pointless "when it cannot or does not productively direct further inquiry" or "when it is not used to construct alternative scenarios to guide a search for evidence which would favour one at the expense of the other" (Currie and Sterelny 2017, 16). Currie further framed this idea in terms of "productive speculation" by referring to it as "empirically-grounded speculation" which "involves formulating a hypothesis that (1) significantly outruns the available evidence, and (2) generates epistemic or empirical goods that increase epistemic traction" (Currie 2018, 289). In line with these points, my study of the history of ancient DNA research suggests that speculation in many cases was productive rather than idle. What is more interesting to note, however, is that this sort of productive speculation often emerged from outside science and was encouraged by press and public interest which then eventually stimulated research within the more traditional laboratory setting.

In the late 1980s and early 1990s, a small but growing group of researchers began to test the limits of DNA preservation in ancient and extinct material with a new molecular biological technique called the polymerase chain reaction (PCR).[10] While PCR was first developed and tested in the US, it was in the UK that ancient DNA research was first backed on a substantial scale in terms of financial and organizational initiatives. PCR produced a feeling of progress among scientists, and the search for the first and the oldest DNA from some of the world's most iconic creatures was soon an artifact of its widespread appeal and application. Crucially, Michael Crichton's 1990 book and Stephen Spielberg's 1993 movie *Jurassic Park* coincided with these events, and its instantaneous popularity situated ancient DNA research and its scientists in the spotlight. In this context, the search for DNA from fossils

[10] PCR uses repeated cycles of heating and cooling to copy DNA. First, heat is used to separate double-stranded DNA into single-stranded DNA. The single-stranded DNA is then exposed to primers. The primers attach themselves to the appropriate sites of the desired DNA to be amplified. A copy of the targeted DNA is produced and used as a template to generate further copies. This process continues with the targeted DNA being exponentially amplified creating millions to billions of copies of the original sequence of interest from only a small amount of genetic material (Mullis and Faloona 1987). See Rabinow (1996) for a detailed conceptual, technological, and financial history of PCR's development.

began to evolve in a research practice under the scrutiny of intense press and public interest.

In the 1990s, the hunt for DNA from fossils was transformed into a high-profile science and technology as a series of studies, published in high-impact journals such as *Nature* and *Science,* reported the recovery of multi-million-year-old DNA from fossils such as amber insects and even dinosaur bone (Cano, Poinar, and Poinar Jr 1992; DeSalle et al. 1992; Cano et al. 1993; Woodward, Weyand, and Bunnell 1994; Golenberg et al. 1990). Riding on the heels and hype of *Jurassic Park*, researchers raced to extract and sequence DNA from the days of the dinosaurs. In the process, the press created opportunities for publicity, but scientists also fashioned their own opportunities for attention. During this decade, scientists were savvy in capitalizing on the celebrity of their fast-growing field in order to secure their success on both an individual and group level. Here, the interplay between science and the media, specifically around the idea of discovering multi-million-year-old DNA, influenced research agendas, publication timing, grant funding, and public perceptions of the search for DNA from fossils.

While there are abundant instances of this connection between science and media and its effect on the development of ancient DNA research, some of the most excellent examples are best illustrated through the search for DNA from insects in ancient amber. In 1991, the University of Nottingham hosted the first official and international meeting on "Ancient DNA" but just before the conference convened, *The New York Times* published a piece about the upcoming meeting, advertising it alongside a recipe for bringing dinosaurs back to life ("Ancient DNA: The Recovery and Analysis of DNA Sequences from Archaeological Material and Museum Specimens" 1991; Browne 1991). In this article, Malcolm Browne interviewed the scientist George Poinar about the connection between the search for DNA from fossils and resurrection: "'Obviously, we couldn't reconstruct an extinct animal today, even if we had all its DNA,' he said in an interview. 'However, my belief is that there are dinosaur cells inside biting flies trapped in amber of Cretaceous age and older. It's just a matter of finding the dinosaur DNA and getting it out.'" (Browne 1991). Poinar, an advocate for the search for DNA from fossils since the early 1980s, had also experimented with the actual extraction of genetic material from amber insects ("Molecular Paleontology: Search for Fossil DNA" 1984; Poinar Jr, Poinar, and Cano 1994; Poinar Jr and Poinar 1994, 73–75). Although these early attempts were ultimately unsuccessful, Poinar, along with rival researchers, returned to the task in the early 1990s in what became a race to recover the oldest DNA (Cano, Poinar, and Poinar Jr 1992; DeSalle et al. 1992; Rensberger 1992).

In 1993, Poinar, along with his son Hendrik Poinar, a student at California Polytechnic State University, and Raul Cano, a microbial ecologist also at California Polytechnic State University, topped the record, claiming to have extracted and sequenced DNA from a 125–135-million-year-old amber-encased weevil (Nemonychidae: Coleoptera) (Cano et al. 1993). They announced it as the oldest DNA ever recovered from an insect in amber. *Nature* published the paper on June 10 of 1993 – one day after the *Jurassic Park* premiere and one day before its public release in movie theaters across the United States (Cano et al. 1993; "Jurassic Park (1993)" 2017; Kirby 2013). The timing produced wide-spread publicity.

The media, as well as practitioners internal and external to the field of ancient DNA research, noticed this timing between the scientific publication and the movie release. In a memoir, George Poinar reflected on the publicity of their publication, recognizing that it "gained instant popularity" and claiming that it "made the front pages of 257 newspapers in the United States and 400 newspapers worldwide." However, he also claimed the timing was a "coincidence" (Poinar Jr. and Poinar 1994, 154). Coincidence or not, the news hit the headlines and left the impression of intentionality. Browne, who consistently covered ancient DNA research for *The New York Times*, commented on the connection: "The report of the achievement is being published today in the British journal *Nature*, one day before the opening of 'Jurassic Park,' a much-publicized movie based on the notion of cloning extinct dinosaurs from their surviving DNA […]" (Browne 1993a). On this point, some scientists saw the timing in a far from positive light. One interviewee offered a rather negative remark about this event: "[…] I thought it absolutely extraordinary that a scientific journal – there was no way it was a coincidence – that a scientific, *a prestigious scientific journal*, like *Nature* would hold on to an article to wait for the opening day of a movie. […] [O]f course, that caused a *huge* media splash" (17-01:02:15). Given that *Nature* is a popular and commercial journal, this makes sense, but this interviewee's perception that the timing was surprising and worth criticizing reflects the notion that some scientists felt that popular outward influences on science could be damaging or less than desirable to the integrity of science. At the same time, however, others viewed this interplay between science and media as a positive phenomenon. Paleontologist Stephen Jay Gould, for example, offered his own observations about the timeliness of it all: "The nearly complete blurring of pop and professional domains represents one of the most interesting spinoffs – a basically positive one in my view – of the *Jurassic Park* phenomenon. […]. When a staid and distinguished British journal uses the premiere of an American blockbuster to set the sequencing of its own articles, then we have reached an ultimate integration" (Gould 1996, 225–226; Kirby 2013, 139). Regardless of the positive, negative, or questionable consequences, press and public attention was a crucial component in the growth of ancient DNA research in terms of raising awareness of this novel, niche, but increasingly high-profile activity.

Jurassic Park also offered other opportunities for publicity which scientists could, and in this case did, use to their advantage in order to promote their research and enhance their reputation (King 1993; Kirby 2013). The *Los Angeles Times*, for example, covered the opening weekend of *Jurassic Park* and specifically spotlighted the interchange between science and science fiction. Journalist Peter King set the scene, describing a packed lobby of movie goers with Hendrik Poinar in the background selling bits and pieces of amber to raise funding for future research: "'Step right up,' barked the stocky, fresh-faced young man in a polka-dot tie. 'Step right up and see the real science. We got it. Right here'" (King 1993). However, the star of the show was Raul Cano: "From Newsweek to 'Nightline' to a newspaper in Lebanon, everyone wanted a piece of the professor" (King 1993). Under the scrutiny, Cano was made well aware of the public's insistent interest in the likelihood of bringing dinosaurs back to life. King quoted Cano: "'And what they all really want me to say,' Cano said, 'is that this is possible, that we can clone dinosaurs'" (King 1993). Cano's answer was far from optimistic. King wrote, "Unfortunately, he explained, this cannot be done now, will not be done ever and, even if it could be done, probably should not be done – for a whole host of moral, ethical and practical reasons. But why spoil a good story?" (King 1993). In this case, these scientists saw *Jurassic Park*'s popularity as a chance to promote their own image, as well as the overall image of ancient DNA research, by placing their work front and center with the recent movie release.[11]

Indeed, other scientists and scientific institutions capitalized on the celebrity of *Jurassic Park* in a way that influenced funding and publicity. In 1993, Jack Horner, vertebrate paleontologist and scientific advisor to *Jurassic Park*, proposed a project to the National Science Foundation (NSF) to search for DNA not from insects in amber but from dinosaur bone. The proposal was in part inspired by some odd observations that Mary Schweitzer, a graduate student working with Horner at Montana State University and Museum of the Rockies, encountered when analyzing a bone fragment in the lab. Under the microscope, Schweitzer observed strange shapes in a thin section from *Tyrannosaurus rex*. Those strange shapes looked like red blood cells, and additional analyses suggested that other soft tissue structures, perhaps even proteins or DNA, might be preserved too. The project, "An Attempt to Extract DNA from a Cretaceous Dinosaur *Tyrannosaurus rex*," asked for approximately $35,000 over a two-year period to

[11] David Kirby highlighted these and other similar interactions and their implications for understanding the relationship between science and media, specifically how science influences, or is in turn influenced by, Hollywood and the blockbuster phenomena. See Kirby Kirby (2003a), Kirby (2003b), Kirby (2013), and Kirby (2014).

try to extract evidence for dinosaur DNA (Horner and Vyse 1993). The grant was funded the same year *Jurassic Park* was released. According to one person on the project, the correlation between the funds and the film was no coincidence: "It's hard to get money. I think NSF gave us money at that time just because of the movie. […] [I]t was the perfect time for it." (16-00:25:25). Not only did NSF approve the award, but they also scheduled a press release to coincide with the opening weekend of *Jurassic Park* (Macintyre 1993, 16; Kirby 2013, 139). *The New York Times* spotlighted the story and quoted a representative from the NSF who confirmed the deliberate timing of the press release with the movie premiere: "'We thought it would be a good opportunity to get the word out on 4 of the 10 dinosaur research projects the N.S.F. is funding this year, including that of Mr. Horner […]'" (Browne 1993b). In the end, scientists could not confirm that they had extracted evidence of dinosaur DNA, but it is important to note that this scientific study, in part funded by enthusiasm for a science fiction movie, was a part of exploring the potential preservation of DNA in ancient and extinct organisms.

The ancient DNA community quickly recognized their role as a science in the spotlight. Although some seemed to enjoy the publicity, others cautioned courting the press and public into believing that science fiction could become reality. In the second "Ancient DNA Newsletter," circulated in 1992 (after the book but before the movie), Russell Higuchi – one of researchers who helped to extract DNA from the quagga – addressed the increasing public interest around the prospect of using DNA from insects in amber to bring dinosaurs back to life. For Higuchi, there was a time and place for speculation, and as a scientist in certain contexts, he appeared to believe that too much unwarranted speculation did more harm than good: "When you get asked (and in the wake of Jurassic Park, the movie, it seems inevitable that some of you will) whether the resurrection of dinosaurs from ancient DNA is possible, I hope you will say it is not. Although it is fun to say, 'in theory, it may be possible (nudge, nudge – wink, wink)', let's get real" (Wayne and Cooper 1992b, 6). He admitted, however, that this was easier said than done: "I myself have been guilty of allowing this romantic – if not gothic – notion, the resurrection of extinct species, to colour reports of our work (it is hard to keep the Media from focusing on that)." Nonetheless, Higuchi urged colleagues to find a balance between this close coupling of professional and popular expectations: "It now seems clear to me that the responsible thing to do is to try as much as possible not to overstate the power of new technology, in the field of ancient DNA or elsewhere" (Wayne and Cooper 1992b, 6).

While media mobilized the practice, it destabilized it too, particularly as researchers tried to transform it into a credible approach to the study of fossils within evolutionary biology. Ancient DNA's unconventional claims and public profile soon attracted suspicion from researchers external to the community. In 1993, for example, Tomas Lindahl, a specialist in DNA degradation and its implications for human health, published a paper in *Nature* about the chemical instability of DNA and its consequences for ancient DNA research. In this article, he highlighted that the processes of hydrolysis, oxidation, and nonenzymatic methylation posed serious problems for the preservation of DNA in fossil material (Lindahl 1993a). In another article, Lindahl more deliberately questioned the credibility of recent research results asserting to have extracted multi-million-year-old DNA. He cynically called these results "antediluvian DNA" (Golenberg et al. 1990; Cano et al. 1992; DeSalle et al. 1992; Cano et al. 1993; Lindahl 1993b). Here, he argued that DNA's biochemistry could not support such longevity, and in the event that it could, Lindahl was deeply concerned about contamination from the external environment. To control contamination, he suggested the sharing of both positive and negative data, appropriate chemical analyses, negative controls, and reproducible results. For Lindahl, the next step must be a conservative one: "Rather than proceed spectacularly further and further back in time with anecdotal reports on single samples, using the notoriously contamination-sensitive PCR, I suggest that the next goal be a convincing report on the amplification of small DNA fragments, say, 100,000 years old" (Lindahl 1993b, 700). During the 1990s, ancient DNA research started to take shape as a new way of studying evolutionary history via conferences, collaborations, newsletters, and financial initiatives. This growth played out publicly in the media spotlight through research publications and media reports in high-profile outlets. By the end of the 1990s, ancient DNA activity had made a name for itself, but the community confronted two important issues, namely how to control contamination and how to control celebrity.

The extreme enthusiasm for ancient DNA research turned to skepticism as scientists internal and external to the practice openly questioned the claims of several high-profile studies. Indeed, a series of studies claiming to have recovered multi-million-year-old DNA from amber insects and dinosaur bone were found to be the product of contamination or irreproducible results. (Cano, Poinar, and Poinar Jr 1992; DeSalle et al. 1992; Cano et al. 1993; Woodward, Weyand, and Bunnell 1994; Gibbons 1994; Morell 1993; Hedges and Schweitzer 1995; Zischler et al. 1995; Service 1996; Austin et al. 1997). These accusations combined led to a dramatic drop in the professional and public confidence in ancient DNA research's credibility. In an effort to standardize the practice and regain its legitimacy, two ancient DNA researchers published a paper in *Science*, titled "Ancient DNA: Do it Right or Not at

All," in which they argued for the adoption of and adherence to proper protocols (Cooper and Poinar 2000).[12] This paper was not just a call for criteria, but a demand to discipline ancient DNA activity in its development as a science in the spotlight. While initially intended to reduce controversy regarding authenticity, the introduction of criteria effectively engendered conflict within the community. Indeed, it divided the community into separate collaborations, conferences, and places of publication. Interviewees say this paper ought to have been titled "Ancient DNA: Do it with Me or Not at All" (11-01:29:15; 21-00:48:30).[13]

To be clear, contamination was a real theoretical and technical issue, but it was an issue further problematized by the celebrity that followed the field. In other words, contamination was more than a professional concern. It was also a public concern because some studies that seriously suffered from contamination or the irreproducibility of results had been, in the 1990s, published in high-impact journals, such as *Nature* and *Science*, and broadcasted across the mass media (Golenberg et al. 1990; Cano et al. 1992; DeSalle et al. 1992; Cano et al. 1993; Woodward et al.1994). For practitioners, their reputation and their science's reputation were at stake.

[12] With concerns for ancient DNA authentication, the "Ancient DNA Lab" became known as a "clean lab," a specially constructed laboratory space designed to minimize contamination of the small amount of genetic material in ancient samples with much more abundant modern DNA. Drawing on guidelines outlined in previous publications, Cooper and Poinar argued that labs handling ancient material must be physically isolated from other molecular or microbial labs containing modern genetic material (Pääbo, Higuchi, and Wilson 1989; Handt et al. 1994; Cooper and Poinar 2000). Other publications expanded on these expectations (Pääbo et al. 2004; Willerslev, Hansen, and Poinar 2004; Gilbert et al. 2005). For example, some scientists said that ancient DNA activity from extractions to experiments should be conducted in a physically isolated lab with positive air pressure and specific ventilation systems to prevent contamination via air flow when entering or exiting the lab. Ideally, these clean labs should be housed in a separate building and away from any building where PCR amplification of DNA is performed. All equipment brought into the clean lab should be decontaminated via bleach or UV irradiation as appropriate. Further, the clean lab should be decontaminated with bleach before and after each entry, and every evening UV lights should be used to further sterilize the space. With every entry to the clean lab, researchers were also required to dress in full body suits with gloves, shoe covers, hair nets, and face masks to avoid themselves from contaminating the specimen during experimentation.

[13] A number of interviewees referred to this division as a schism between the "believers" and "non-believers" (5; 6; 23; 28; 36). This division between "believers" and "non- believers" centered around debates about contamination and scientific standards for avoiding it. While both sides were aware of contamination, they differed in the degree they employed methods to test for ancient DNA authenticity. Roughly, the "non-believers" were suspicious, even dismissive, of research results produced by the "believers." The "non-believers" more or less viewed research by the "believers" as less rigorous and therefore, less reliable. These terms – "believers" and "non-believers" – are categories that interviewees on both sides of the schism used in reference to themselves and others. There are some scientists who also refer to the schism as a difference between the "haves" and "have nots," and while not all interviewees used both or even one set of terms to describe the split, they all recognized the split, though to differing degrees, and its influence on the sociology of their science. However, it is important to note that the line between the "believers" and "non-believers" is not necessarily hard and fast. It is permeable. Indeed, some scientists tried to collaborate across the schism. Nonetheless, the caricature of "believers" and "non-believers" helps scientists make sense of an important issue, concerns about contamination, and its influence on ancient DNA's disciplinary development. On this point, it is by no means the only map of interactions that interviewees try to draw, or that can be drawn, throughout the history of this community.

Consequently, scientists built boundaries via protocols and even rhetoric of ridicule and narratives of negation to try to demarcate credible from less credible research in response to concerns about contamination as well as celebrity.

But at the turn of the century, the standards employed to avoid contamination and confirm authenticity were transformed by the innovation of a new technology called next-generation sequencing (NGS).[14] While PCR requires specific DNA fragments of sufficient length to be present in a sample, NGS is untargeted, allowing every DNA fragment present to be sequenced. As a result of NGS, researchers could now recover millions of sequences at higher yield and in a fraction of the time. This allowed better estimation of the percentage of endogenous and exogenous DNA by searching for signatures of molecular degradation or post-mortem damage characteristic of authentically ancient DNA. Consequently, the technology reframed concerns about contamination. One scientist, for example, put it this way: "So, now it's not only a question of having controls [...]. You can actually look at your data and determine whether you have a contamination problem or not, right?" (7-00:17:30). With the advent of NGS, researchers were quick to adopt the new technology and adapt it to search for DNA from fossils in order to overcome some of the previous limitations and contamination issues associated with PCR (Poinar et al. 2006; Cooper 2006). In doing so, these scientists sought to establish ancient DNA's legitimacy among professional and public audiences alike.[15]

Indeed, NGS ushered in a new era of exploration as researchers' focus shifted from the science of ancient

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[14] Next-generation sequencing (NGS) is the general term used to describe a variety of technologies that use parallelized platforms to sequence more than one million short reads of DNA (50-400 base pairs) in a single run. There are a number of NGS platforms varying in their chemistry and specific sequence read technologies. Two instruments that were widely used in ancient DNA research in the late 2000s were Roche (454) GS FLX, a technology based on parallel pyrosequencing, and Illumina (Solexa) Genome Analyzer, a method based on reversible terminators. The 454 technology generates longer reads of DNA (over 400 base pairs) but is somewhat error-prone in homopolymeric regions (e.g. CCCCCC), while Illumina generates shorter reads of DNA (100-150 base pairs), but in greater numbers. See (Margulies et al. (2005) and Knapp and Hofreiter (2010).

[15] In a recent paper, Alexandra Ion problematizes the idea of ancient genetic or genomic data as being a "holy grail" in the sense that this kind of data can always provide new and better answers to old archeological questions (Ion 2017). Ion explained, "Given the fragmentary nature of the material record, archaeologists are ever-expanding their intellectual and methodological tool-box, going beyond the disciplinary boundaries, and involving themselves in what are often called interdisciplinary projects. Alison Wylie and Robert Chapman (2016: 15) raise in their latest book the interesting point that this phenomenon is closely tied to an 'epistemic anxiety' inherent to archaeological reasoning, namely the fear that there is only so much we can learn about the past, especially if this knowledge is to be 'objective'. I would claim that in archaeology we now see a structuring of discourses around interdisciplinarity as a way of framing relevance and innovation in the face of the 'manifold and messy' problems of life and society […]" (Ion 2017, 88). Drawing on the example of King Richard III and a series of studies that use ancient molecular data to shed light on the Neolithic Revolution, Ion questioned whether this genetic data from the "hard sciences" is successfully being integrated with the historical and cultural contexts that archeologists are traditionally interested in investigating. She also brought attention to the important issue of how these big databases bias archeologists in terms of the types of questions they ask and the scales of analyses they employ.

genetics to the study of ancient genomics.[16] Equipped with this technology, scientists entered a race to sequence the first genomic data from ancient plants, animals, and diseases to human Paleo-Eskimos, Aboriginal Australians, and famous historical figures like King Richard III (Gilbert et al. 2008; Gilbert, Drautz, et al. 2008; Miller et al. 2008; Rasmussen et al. 2010; Rasmussen et al. 2011; Bos et al. 2011; Pedersen et al. 2014; Rasmussen et al. 2014; Willerslev et al. 2014; King et al. 2014). Using NGS, scientists sequenced the first genomic data from an archaic human, the Neanderthal (Green et al. 2010), and were able to show for the first time that modern humans and our Neanderthal interbred. They also sequenced the first genomic data from a Denisovan, an extinct hominin species whose identity as a distinct archaic human species was uniquely obtained exclusively from DNA, without a fossil record (Krause et al. 2010; Reich et al. 2010; Gibbons 2012; Gokhman et al. 2014). Meanwhile, other research has shed light on the behavior of our early ancestors, including Mesolithic and Neolithic hunter-gatherers, while also exploring transformations in human cultural practices such as milk consumption which have directly impacted our evolution in terms of selection for lactase persistence (Izagirre and de la Rúa 1999; Haak et al. 2005; Burger et al. 2007; Bramanti et al. 2009; Haak et al. 2010; Skoglund et al. 2012; Warinner et al. 2014; Jones et al. 2015; Malmström et al. 2015). Much work has also explored our interactions with animals through time by interrogating genetic signals for domestication in pigs, cattle, and dogs on large global and temporal scales (Leonard et al. 2002; Bollongino et al. 2006; Larson et al. 2007; Scheu et al. 2008; Larson et al. 2012; Larson et al. 2014; Skoglund et al. 2015). According to some scientists and journalists, these works have led the way towards a revolution in our understanding of human origins, evolution, and migrations (Stoneking and Krause 2011; Stringer 2012; Veeramah and Hammer 2014; Gibbons 2015). Although these findings have made considerable conceptual contributions to understanding evolutionary history, these studies, many published by high-profile journals such as *Nature* and *Science*, have also been followed by the celebrity spotlight. This race for the *first* or the *oldest* genome (as well as the race to sequence the *most genomes*) and the accompanying media attention surrounding it, shared striking

[16] The study of ancient DNA data had previously been limited to the study of mitochondrial DNA (mtDNA) and sometimes nuclear DNA (nuDNA). Recently, however, the potential to sequence whole genomes via high-throughput sequencing technologies has allowed researchers to produce an increased amount of higher quality data (from several sequences to billions of sequences) that has allowed them to more accurately quantify contamination, and therefore guarantee DNA authenticity. It has also allowed them to study the entire genomic make up of an organism, more similarly to how modern genomes are analyzed, and this has provided more detailed answers to questions regarding phenotype, adaptation and evolution together with documenting when migration and gene flow events have occurred. As a result, researchers recently reported that the "field" has "entered the new era of genomics and has provided valuable information when testing specific hypotheses related to the past" (Der Sarkissian et al. 2015).

similarities to the 1990s' search for the first or the oldest DNA.

However, one key difference between the PCR and NGS-era was that practitioners went from having little data to having almost too much. High-throughput sequencing technologies could produce an astounding amount of data that required both large amounts of data storage but also required researchers to seek or learn specialist computational and statistical skills in order to analyze it and apply it to questions in evolutionary biology. From a field dominated by the laboratory scientist, ancient DNA research has moved to the realm of the computer scientist, bioinformatician, and statistician. One interviewee presented this perspective: "Processing is completely different because before I could still look at each sequence by eye and edit them by hand, but now we have [...] billions of sequences and you have to do everything by bioinformatics. So, that has changed completely. [...]" (15-00:35:30). According to practitioners, the growing availability of samples combined with the increasing ability to sequence genomes rapidly superseded their aptitude to analyze the data. It sometimes superseded the question that they could ask of the data, too. One interviewee, for example, offered this opinion: "People are going *over* the top because they can – just sequencing the living crap out of absolutely everything. So, we're in this kind of exploration phase again, where it's like, 'Grab as much data as you possibly can, hire a great bioinformaticist, and then start asking questions in the resulting data sets'" (22-01:18:00). After a nearly thirty-year history of disciplinary development towards scientific legitimacy and maturity, it appeared that researchers had now entered a new era of experimentation as they tested the limits of NGS applied to ancient and extinct organisms and their populations.

From the 1980s to the turn of the century, scientists were very much driven by data in terms of the samples they had access to and the amount of informative genetic information that could be recovered from them via the technology of PCR. At the same time, however, some scientists felt that the search for ancient DNA was driven by the celebrity of the science as practitioners pursued the first and the oldest DNA from some of the most iconic species. While the availability of fossils and the technology of PCR were both vital to the production of research results, the celebrity surrounding specific samples, like amber insects and dinosaur bone, coupled by the drive to be first in the field, propelled this practice into motion. To be clear, however, the data-driven and celebrity-driven nature of ancient DNA research was not unique to the 1980s and 1990s alone. Like the PCR-era, the NGS-era of ancient DNA research can also be characterized as an era of data-driven and celebrity-driven research. In the earlier PCR years, they were driven by a desire for data but also limited by a lack of data, while in the later NGS years, they were driven and inundated by the enormous amounts of genomic data that could be generated from a single sample.

Despite the continuity between the two eras of scientific and technological change, interviewees, in reflecting on the historical and philosophical growth of ancient DNA research, often draw a distinction between the early years of this practice and its standing today as what they view to be a more question-driven, and therefore more mature, science. As far as these interviewees were concerned, being question-driven was more desirable than being data-driven and celebrity-driven.

The take-home message from this section is that the search for DNA from fossils, throughout its thirty-year history, can be characterized as a data-driven and celebrity-driven practice. So far, this history demonstrated the degree to which scientists in search of DNA from fossils were primarily interested in pursuing data in terms of their access to samples and the availability of technology. Crucially, it also demonstrated that scientists, as well as major journals such as *Nature* and *Science*, were motivated by the celebrity that surrounded the science of ancient DNA research. Indeed, I argued that celebrity can, and in the case of this history did, influence the process and practice of science over a prolonged period of time in terms of its influence on research agendas, publication timing, grant funding, and public perceptions of the search for DNA from fossils. The next two parts of this article will investigate researchers' recollections and philosophical perspectives of their history, then will explore the role of celebrity and credibility with attention to its implications for philosophical questions regarding scientific practice.

An answer looking for a question

In response to credibility concerns, ancient DNA researchers engaged in "boundary-work." Thomas Gieryn initially introduced the idea of "boundary-work" by drawing on a series of studies in which he analyzed early natural philosophers' and scientists' struggles to demarcate science from non-science or from what they viewed to be less credible approaches to science (Gieryn 1983). As a result of his research, Gieryn described boundary-work in these terms: "Put bluntly, a sociological explanation for the cultural authority of science is itself 'boundary-work': the discursive attribution of selected qualities to scientists, scientific methods, and scientific claims for the purpose of drawing a rhetorical boundary between science and some less authoritative residual non-science" (1999, 4–5). For Gieryn, there was no one and only way to do science but rather different ways to draw or redraw the boundaries of what we view to be science. On this point, he also argued that individuals often engage in what he coined as "double boundary-work" in which researchers build boundaries on two fronts in response to two different but perhaps not entirely unrelated issues that appear to affect their autonomy (Gieryn 1999, 63). Sure enough, in the history of ancient DNA research, researchers engaged in “double boundary-work” in response to both contamination and celebrity concerns.

Although scientists involved in the search for DNA from fossils built boundaries around their practice through the development of criteria in their day-to-day activities in the lab, their memories of their history are also full of boundary-work. Reflecting on their thirty-year history, interviewees portrayed the practice in its early days as “an answer looking for a question” rather than a question looking for an answer (2-01:03:00). For interviewees, there were several studies in which the answers, the DNA, seemed to supersede the question that could be asked of the DNA.[17] In reference to some of the scientists who appeared to favor this data-driven approach, one researcher remarked, “They may have a research question. […] But sometimes it’s even *pre*-getting-a-research-question. It’s like, ‘Let’s study these. Let’s see if there’s DNA in these fossils.’ [...].” This interviewee shared a story as an example: “I remember one occasion when one of the well-known ancient DNA researchers said to me, ‘What species should I study? Mammoths are being done. What species isn’t being done?’ [...] [I]t got to the point to where there would be PhD students and you could see the supervisor thinking, ‘What species hasn’t anyone done yet? Nobody’s done musk ox. Ok. You do musk ox.’ *Without a very clear question*.” For this interviewee, this data-driven approach seemed to be partly propelled by press and public interest in charismatic creatures that would yield data but also be likely to lead to high-impact publications: “[...] I’ve seen several examples of ‘let’s blitz this species.’ We give a PhD student this species. They collect fossils from all over […], they do the DNA, they draw up trees, and *then* they start to ask questions [...]. And then the supervisor is usually then looking for a high-impact angle. [Laughs]. It is a slightly odd way of doing science” (3-00:44:30). This interviewee, as well as others, portrayed the practice in its early years as a sample-driven, technology-driven, and even celebrity-driven practice. In these cases, they seemed to be criticizing this particular behavior.

However, with the introduction of NGS and subsequent shift from PCR in the early 2000s, some scientists seemed to think this data-driven strategy was changing. In 2013, an international and interdisciplinary group of researchers gathered together at the Royal Society for a commemorative conference, “Ancient DNA: the first three decades” (“Ancient DNA: The First Three Decades” 2013). In the introduction to the special series of papers

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[17] This phrasing presupposes that ancient DNA data holds relevant molecular information about the organism it came from and its evolutionary history. However, scientists, after extracting the DNA, must still make sense of the DNA by analyzing, interpreting, and appropriately applying it to questions in evolutionary biology. In other words, the answers are not explicit in the data themselves. Scientists must manipulate the data in order to make meaning.

produced by this meeting, the conference conveners argued that the field was no longer a curious phenomenon but now a credible practice: "In the past, a large number of ancient DNA studies were either purely technical, or one-off historical puzzles but, as we can see from the contributions to this *Theme Issue*, this is no longer the case, and ancient DNA researchers are now addressing a growing number of important scientific questions" (Hagelberg, Hofreiter, and Keyser 2015). According to one interviewee, NGS freed researchers from PCR's constraints regarding contamination, thus allowing them to focus on the biological questions rather than the technological limitations: "[...] [F]or the first time in history, I think we're not driven at all by the technology because the technology is permissive today. We are driven by the question we can answer with the technology. [...] (Well, it's not really that yet, but it's *close* to it.) [...]" (8-00:18:45). According to another interviewee, it was more than the technology-driven nature of the practice that had passed: "I think that we are question-driven rather than sample-driven." For this scientist, the early days were "sample-driven" but "now that all the low-hanging fruit have been picked it's more question-driven" (43-00:10:30). While interviewees recognized the role that technology and samples had played in the practice of ancient DNA research, they viewed this shift to a more question-driven approach as a mark of maturity. Maturity was desirable to scientists, especially amidst credibility concerns.

However, the search for DNA from fossils, even in its early era as a data-driven science (in terms of samples and technology), was in fact a question-driven one too. By surveying early studies, it is clear that researchers were indeed driven by questions but questions regarding the theoretical preservation and potential extraction of DNA from ancient and extinct organisms. Further, answering these questions was no small feat. Throughout the 1980s and 1990s, scientists confronted extreme technical challenges. These questions were technical in nature as scientists sought to discover what was possible regarding the preservation and extraction of DNA from ancient skins, tissues, and even bone. But for some studies, the questions also took on a biological bent. For example, the 1984 quagga study was initiated as a theoretical and technical challenge, but the specimen, *Equus quagga*, was specifically selected in order to test a hypothesis about the evolutionary history of an extinct species, one that was previously inconclusive based on fossil data alone (Higuchi et al. 1984). Likewise, researchers working with one of the early studies to try to extract DNA from insects in ancient amber had chosen a specific termite specimen, *Mastotermes electrodominicus*, in order to test hypotheses of insect evolution and extinction (DeSalle et al. 1992). In these cases, there was a biological question, but it was often secondary to the technical achievement of recovering DNA from the fossil in the first place. In the early days, it was nearly necessary for the technical question to take precedence as the biological or historical question could not be answered without it.

Yet in their memories of their history, some interviewees tried to draw a line between what they viewed to be a data-driven past and a more question-driven present in order to place some temporal and methodological boundaries around the evolution of their practice. In other words, this language of an answer looking for a question, rather than a question looking for an answer, can be characterized as an extended episode of retrospective boundary-work. This language was a way in which scientists sought to compose a narrative of ancient DNA activity, intentionally or unintentionally, by drawing a line between its emergence and what some scientists see now as its more or less established status today. Here, scientists attempted to draw a distinction between what they saw as a data-driven and celebrity-driven phase of research versus a more question-driven methodology. The sometimes derogatory or dismissive comments by some interviewees about earlier practitioners, or even practitioners today, as scientists merely chasing samples, technology, and even celebrity can be viewed as an attempt to draw out their own achievements, thus drawing methodological and epistemological distinctions between ancient DNA's past and present, and in the process aligning themselves with one scientific approach rather than another. According to some of these interviewees, being question driven rather than sample, technology, or celebrity driven was a hallmark of scientific maturity. They engaged in this sort of retrospective boundary-work because they were concerned about their credibility within evolutionary biology.

In reality, however, there is actually more continuity between researchers' past and present approaches to the study of DNA from fossils. Indeed, it appears that data-driven, celebrity-driven, and question-driven approaches have been, and are being, employed simultaneously. These mixed methods are not incompatible with one another, and they often go hand in hand.

Although some scientists argue for a more question-driven and more mature area of research, other evidence, including other interviewee quotes, suggest that ancient DNA research is still in fact very much driven by the available samples and technology. Indeed, according to several scientists, ancient DNA activity still seems to be an answer looking for a question as opposed to question looking for an answer. In 2015, for example, a team of researchers – including Morten Allentoft and Eske Willerslev – sequences 101 ancient human genomes ranging from 700 AD to 3000 BC with the ultimate goal was of testing hypotheses about evolution and migration during a time when new tools and traditions had surfaced, then spread across Eurasia (Allentoft et al. 2015). While question driven, the project was also very much driven by the samples and technology. Researchers went over the top to generate more genomes than necessary simply because they could. Reporting for *Nature,* Ewen Callaway specifically spotlighted this research and took note of this data-driven approach (Callaway 2015a). Callaway quoted Allentoft: "'We could have stopped at 80,' says Allentoft. But 'we thought, "Why the hell not? Let's go above 100." ' " (Callaway 2015a). With NGS, the issue was no longer too little data but rather too much data. On this particular point, Callaway quoted Greger Larson at Oxford University: "'It's an interesting time, because the technology is moving faster than our ability to ask questions of it,' says Larson, whose lab has also amassed around 4,000 samples from ancient dogs and wolves to chart the origins of domestic dogs. 'Let's just sequence everything and ask questions later.'" (Callaway 2015a). Indeed, this trend continues today (Olalde et al. 2018; Mathieson et al. 2018).

Although there is certainly continuity between ancient DNA's data-driven past and present, the primary difference between its early years and today is that the situation has shifted from scientists having too little data to having too much data. One researcher, for example, shared this story about methodology: "[...] We got some new genomes and it wasn't question driven anymore. We didn't have a look at those genomes because they were the key to a question, but [because] they were good samples and we could get whole genomes [...]" (13-00:42:00). For a second scientist, this approach was a general consequence of new opportunities: "I think whenever a new technology comes on board there's a lot of 'Ta-da!' Hey, we analyzed this stuff with this new technology.' And it's really driven by the labs that have access to the technology and the samples [...]." But for this same scientist, this approach could also be attributed to other areas of science, particularly recent genomic research today: "I don't think that's necessarily unique to ancient DNA. If you look at genome sequencing, genome sequencing is very much, 'Ta-da! Here's a genome! Look at all these data.' And then they go off and ask questions" (30-01:27:50).

Today ancient DNA's data-driven methodology, inspired by good quality samples and new opportunities thanks to high-throughput technology, seems to be common across the field of ancient DNA research specifically and genomics more generally. While these interviewees did indeed describe ancient DNA activity as being a data-driven sort of science, other researchers, reporters, and science studies scholars – particularly philosophers – have also taken notice of this data-driven approach as being a shared approach across the biological and biomedical sciences thanks to the rise of big data (Kell and Oliver 2004; Weinberg 2010; Leonelli 2012; Strasser 2012; Leonelli 2016). Their accounts, like my interviewees' examples and explanations of ancient DNA activity, not only take notice of this strategy but also ask whether this data-driven approach is a novel approach or even desirable approach to scientific study.

Celebrity and Credibility in Data-Driven Practice

In this third and final section, my goal is to introduce the history of ancient DNA research, particularly the role of celebrity and credibility, into the current conversation among scientists and philosophers of science about the role of data-driven research in the biological sciences. In doing so, I do not intend to do justice to the scientific and philosophical elements that this rich discussion requires. However, I do intend to raise some points of connection between this history of ancient DNA research and what philosophers of science have said about the nature and implications of contemporary data-driven inquiry. So far, this article has demonstrated the degree to which scientists in search of DNA from fossils were very much driven by data in terms of access to samples and availability of technology. It has also demonstrated that scientists, as well as major journals such as *Nature* and *Science*, were also motivated by the celebrity that surrounded the science of ancient DNA research. Consequently, this section argues that this data-driven and celebrity-driven methodology matters to the epistemology of science.

As the search for DNA from fossils evolved from the 1980s to today, researchers responded to its technological challenges and status as a public-facing practice. Here, scientists were concerned about "contamination" in both a technical and a social sense. For example, doubts over ancient DNA authenticity and the reproducibility of results, specifically in the 1990s, placed the practice's credibility on the line. In reaction, a handful of researchers tried to "discipline" the discipline via criteria of authenticity.[18] At the same time, celebrity was also a crucial component of ancient DNA's disciplinary development, and although media mobilized the practice, it destabilized it too. In reference to this, some scientists felt that media interest or influence was a second source of contamination that affected the credibility of their research. Both these matters, contamination and celebrity, courted controversy, and consequently questions of scientific credibility, around the search for DNA from fossils.

Crucially, the issue was not about whether ancient DNA research was science or non-science, but whether it was a credible versus non-credible approach to the study of fossils. The answer was far from simple as ancient DNA activity was tied up in a long history of scientific, press, and public influences and expectations. Ancient DNA's history had unfolded on a public platform and this meant that scientists felt they could not solely rely on technology or methodology in terms of protocols or verification as a way to draw lines between credible and non-

[18] In 2000, Alan Cooper and Hendrik Poinar published a paper in *Science* titled "Ancient DNA: Do it Right or Not at All" that detailed a strict set of criteria for avoiding or detecting contamination in the lab.

credible research. They felt their public profile required a public response about the proper practice of ancient DNA research (Lister 1994; DeSalle and Lindley 1997; Cooper and Poinar 2000; Pääbo et al. 2004; Hebsgaard et al. 2005). As a result, practitioners built boundaries via criteria in the lab in response to contamination concerns, but they also built boundaries via rhetoric, especially through their memories of their history, in response to celebrity concerns.

Overall, demarcation mattered for scientists because it signified growth and research relevance within evolutionary biology. In other words, scientific maturity signified legitimacy, and this mattered for ancient DNA researchers coming out of a thirty-year history of credibility contests over contamination and celebrity concerns. This was not unusual. In the philosophy of science, the demarcation debate has a long history full of discussions about the more or less correct ways, and even wrong ways, of practicing science (Popper 1959; Kuhn 1962; Lakatos 1970). In all of this, hypothesis testing as a criterion for proper scientific practice often comes out on top, taking a privileged position over other methods of inquiry. Much of this emphasis on generating and testing hypotheses can be attributed to Karl Popper's influence among philosophers of science and scientists themselves. Despite the many counter arguments to Popperian philosophy (Lakatos 1970; Feyerabend 1975; Laudan 1981), his criterion of falsifiability, also understood as the testability or refutability of a hypothesis or theory, still holds strong as a benchmark for demarcating science from non-science, as well as good science from bad science (O'Malley et al. 2009; Haufe 2013). Indeed, with the rise of big data across the scientific disciplines, and what many refer to as a new mode of data-driven scientific research, the place and preference for hypothesis-driven or question-driven inquiry has come back into the spotlight (Leonelli 2012; Leonelli 2016).

To this end, it is important to note that my objective is not to judge whether this data-driven and celebrity-driven approach was, or indeed still is, a positive or negative phenomenon in the world of ancient DNA research. However, it is my objective to highlight that *scientists practice science* in a way that is influenced by a want and need for both data and publicity, and that *they themselves* interpret these influences as having positive, negative, or even questionable effects on the production of knowledge and their scientific status within evolutionary biology. In my interviews, some scientists seemed to believe that ancient DNA research has come of age and that it is now a much more question-driven, rather than a data-driven, sort of science. It is my view that they drew this distinction to assert their legitimacy within evolutionary biology in light of what they saw to be a data-driven past. However, I suggest that ancient DNA activity continues to be data-driven especially in terms of technology. The difference is that the situation has shifted from having too little data to having almost too much data.[19]

Philosophers today are increasingly interested in this phenomenon of data-driven science. In 2012, for example, a group of scholars approached this topic of data-driven research with an interest in identifying its characteristics as well as its causes and consequences for the production of scientific knowledge. They were also interested in trying to understand the role that hypotheses and theories played in this sort of methodology. According to their studies, they found that data-driven sciences often value 1) the process of induction from given data as a legitimate approach to scientific inference, and 2) the role of technology as a means of analyzing then extracting significant patterns from the given data. In all of this, philosophers have asked a further question of this particular phenomenon: Does this data-driven approach constitute a novel approach to scientific inquiry or does it share similarities with past research practices?

In his commentary on a selection of these papers (Muller-Wille and Charmantier 2012; Sabina Leonelli and Ankeny 2012; Keating and Cambrosio 2012), Bruno Strasser looked for overall similarities and differences among data-driven sciences over the past few centuries (Strasser 2012). As far as he was concerned, early natural history "wonder cabinets" were not so dissimilar from "electronic databases" of today. According to Strasser, "Renaissance naturalists were no less inundated with new information than our contemporaries." Indeed, "The expansion of travel, epitomized by the discovery of the New World, exposed European naturalists to new facts that did not fit into the systems of knowledge inherited from the Greeks and Romans" (Strasser 2012, 85). Through a study of Carl Linneaus, Staffan Müller-Wille and Isabelle Charmantier specifically spotlighted the data-driven nature of eighteenth-century natural history in terms of the various strategies he employed to organize and analyze what can be could be called an "information overload" of new species data (Muller-Wille and Charmantier 2012). First, these authors drew attention to the fact that Linneaus used new tools – such as dichotomous diagrams, files, and indexes – to help control the amount of data under study. Interestingly, however, these tools, initially intended to control the amount of data, facilitated an influx of data. Here, the authors pointed out that in the midst of this data deluge, Linneaus also attempted to make sense of the information by generating a hypothesis, namely the genus concept as a distinct category, as a further means for organizing the information, then classifying and comparing organisms

[19] This shift from "too little data" to "too much data" is meant to be understood as a comparison between ancient DNA research's past and present. Even if researchers are able to produce more data, comparatively speaking, the data is still often of poor or patchy quality. This requires researchers to find ways of handling and analyzing the data. Today, there is much more data than before, but the amount of ancient DNA data if compared to the influx of modern DNA data is still far off.

accordingly. Strasser put the point this way: "In other words, Linnaeus may have been driven by his data, but his approach was not exclusively data-driven" (Strasser 2012, 85). This example showcased that ways in which data-driven inquiry may not be so new to contemporary scientific and technological practices. Rather, it showed that natural history has a long history of producing, then dealing with, information overload. Further, it showed that natural historians, like contemporary scientists, were also open to pursuing mixed research methods from data gathering and hypothesis testing in order to make sense of the world around them.

Despite this continuity, however, Strasser also identified distinct differences between past and present data-driven practices in the sciences. For Strasser, three features set the contemporary data-driven sciences apart from former natural history practices: one) the data analysis today is done by researchers from disciplinary backgrounds different from the individuals who produced it, two) the data analysis very much depends on the use and understanding of statistical tools, and three) the data is primarily generated from inside the lab and not the field as was typical of previous natural history practices (Strasser 2012, 86). Strasser also attempted to explain why so many scientists view data-driven inquiry today as uniquely overwhelming and even revolutionary: "To conclude, it is mainly because the experimental sciences took the upper hand over natural history in the late nineteenth century and have since come to dominate the public perception of science that data-driven research is now perceived as a novel feature of twenty-first century science." However, historically-minded case studies demonstrate that this data deluge is nothing new: "Natural history had been 'data-driven' for many centuries before the proponents of postgenomics approaches and systems biology began to claim the radical novelty of their methods" (Strasser 2012, 87).

In her recent book, *Data-Centric Biology: A Philosophical Study,* Sabina Leonelli made an additional observation about the data-driven sciences of today. According to Leonelli, data-driven sciences are not necessarily interesting because they are data-driven but because of the social, organizational, and institutional structuring required to produce, then analyze, the massive amounts of data that are a part of the practice (Leonelli 2016). In her case study, she focused on plant system databases in model organism biology to map out what she called data-journeys. Here, she was interested in outlining the ways in which researchers across the board worked together to collect, integrate, analyze, and share various sources of data that eventually would be used for different scientific purposes. In other words, Leonelli's focus on data-driven science was much more about the process rather than the product.

Although a much more detailed analysis is required to make the point, ancient DNA researchers seem to be making moves to operate under similar large-scale organizational systems. Indeed, ancient DNA researchers, in light of new whole-genome sequencing technologies and techniques, are faced with new challenges and are trying to generate a new kind of institutional infrastructure in response to them.[20] Indeed, ancient DNA researchers are finding that a whole host of resources are required in order to go from a sample to a sequence to a meaningful scientific analysis in a reasonable time frame. In response to opportunities offered by technology, some scientists are responding by building large-scale business-like operations that oversee the production and distribution of ancient DNA data. Svante Pääbo's lab at the Max Plank Institute for Evolutionary Anthropology, Eske Willerslev's lab at the Centre for GeoGenetics in the Natural History Museum of Denmark, and David Reich's lab in the Department of Genetics at Harvard University are examples of the industrial operation that ancient DNA research can require. However, much of this go-big-or-go-home approach is of their own doing. In 2015, Reich was named one of *Nature*'s top ten people who mattered (Callaway 2015b). In this recent report, Reich was called a "big thinker" who "helped to turn ancient genomics from niche pursuit to industrial process" (Callaway 2015b). Sure enough, in his new book, *Who We Are and How We Got Here: Ancient DNA and the New Science of the Human Past*, Reich was open about his objective to make "ancient DNA industrial" by transforming his lab into an "American-style genomics factory" (Reich 2018, xvii). Throughout its history, ancient DNA research has been a data-driven science (in its interplay with other methods), but this shift to ancient DNA research as an industrial operation highlights the changing ways in which the field has been or might be data-driven in the future. In other words, ancient DNA research is still data-driven, but we are witnessing a change in the data-driven nature of ancient DNA research in terms of how it is actually approached and carried out in practice. Over a thirty-year-period, the practice has evolved from one) an anomaly and initial effort to try to extract DNA from fossil material with the technology of PCR to

[20] Most recently and obviously, new whole-genome sequencing technologies have pushed ancient DNA researchers to seek new skills in statistics, bioinformatics, and population genetics in order to analyze the massive amounts of data that can now be extracted from hundreds of samples thanks to technology. However, it is important to note that ancient DNA researchers are much more than a user community of the machinery. Here, they are committed to developing new methods that can be used in the lab to optimize the extraction and sequencing process. In other words, although new technologies and techniques are critical to ancient DNA activity and the extent to which data can be made available and analyzed, practitioners do not just draw on developments in other fields but instead are active individuals in adapting these innovations for their own purposes. Ancient DNA requires manipulation and management of data namely because the nature of ancient DNA is not the same as that of modern DNA. Indeed, the extraction, sequencing, and analysis of degraded and damaged DNA requires a specialist skill set to understand the biochemistry of DNA damage in order to be able to correctly infer how differences between sequences relate to differences among individuals and populations over time.

two) an intentional effort to do more because of the innovation and adoption of NGS to three) a business-like philosophy, at least in some research groups, interested in doing the most in an attempt to make the science a truly large-scale industrial and automated process. However, this business attitude is not without its critics (Callaway 2018). Here, archeologists, paleontologists, and curators are some of the most concerned about the intensity of sampling.[21] Yet for better or worse, data-driven approaches, in whatever form or function, have been and continue to be a principal part of the search for DNA from fossils.

Traditionally, philosophers of science and scientists and have tried to divide scientific inquiry into two categories, one being data-driven and the other being hypothesis-driven. This binary view, however, is changing as scholars have also brought attention to the fact that data-driven research is often pursued in combination with other modes of scientific inquiry. For example, a number of scholars have addressed the role of exploratory experimentation in the data-driven sciences (Calvert 2012; Krohs 2012; Callebaut 2012; O'Malley and Soyer 2012). In his case study of convenience experimentation in systems biology, Ulrich Krohs made the point that all science does not necessarily need to be hypothesis driven at all times. Krohs, arguing against the classical conception that the goal of experimentation is to test hypotheses, suggested that "other modes of experimentation" such as the "searching mode of exploratory experimentation" (Burian, 1997; Steinle, 1997)" as well as "data driven research (Leonelli, 2012)" can be considered as "serious epistemic strategies, besides, and in combination with, hypothesis driven research" (Krohs 2012, 53). Other philosophers also argue that we should make more room for an interplay of approaches when it comes to understanding the process and practice of science. Maureen O'Malley put the point this way: "It is possible that theory-driven hypothesis testing has been conceived of by scientists, science funders and philosophers in a way that does not exist in practice (and never has), and that it is closer to and involves more interplay with exploratory experimentation as well as natural history experimentation than we have tended to think"

[21] To be sure, archeologists, paleontologists, and curators are vital to the pursuit of DNA from ancient and extinct organisms. They are valuable for sample access as well as knowledge on the historical and biological background needed in order to give context to the data obtained from a specific sample. However, there is a tension between those researchers responsible for conserving specimen collections and those interested in sampling organisms for genetic information. This is because sampling for ancient DNA is destructive to the specimen, and this was certainly a concern in the early years of ancient DNA research. See Graves and Braun (1992). Museums value their collections for their rarity, and their main mission is to conserve past and present specimens for future generations to study or enjoy. While molecular methods offer new opportunities for curators to make new uses of old collections, taking samples of skin, tissue, or bone can damage often rare or important specimens. This presents a clear challenge to researchers and curators to find a compromise between their motives. To a certain extent, this challenge can cause a significant dichotomy between the large labs in ancient DNA research who are driving more and more specimen sampling and those curators who are trying to minimize damage to museum collections. See Freedman, van Dorp, and Brace (2017).

(O'Malley 2007, 345). In this history of ancient DNA research, interviewees involved with the search for DNA from fossils tend to lean on a distinction between data-driven and hypothesis-driven methodologies in order to draw a line between their earlier and later phases of research. They do this to assert their legitimacy within evolutionary biology in light of what they see to be a data-driven and less credible past. Although practitioners' boundary-building was sociologically important for establishing their identity, legitimacy, and authority within the scientific community, this boundary-work was also philosophically naïve given that philosophers today no longer necessarily see a distinction between data-driven and hypothesis-driven research.

I agree with recent philosophical viewpoints that argue the need to make room for more forms of inquiry in scientific practice, and I argue that a celebrity-driven strategy can be considered a "serious epistemic strategy" that researchers, as well as editors and funders, employ when making choices about research agendas, publication acceptance, and grant funding. My point is not to claim that all research was guided by, or needed to be guided by, its potential to consistently attract press and public notoriety. Rather, my point is to suggest that celebrity can be a crucial consideration behind researchers' decisions that influences their process of data gathering, hypothesis testing, technological development, and exploratory experimentation.

On this point, this history of ancient DNA activity demonstrates that the traditional distinctions and debates between data-driven and hypothesis-driven research are not always sufficient for understanding the process and practice of science. Rather, these methods can be employed simultaneously. Specifically, I have demonstrated that scientists in search of DNA from fossils have engaged in *data-driven science* in terms of pursuing valuable samples, state-of-the-art technologies and techniques, and the molecular information (DNA) that can be recovered from accessible samples using existing technologies. In the process, I have demonstrated that scientists have also engaged in *question-driven science* by asking and answering questions about the theoretical preservation and potential extraction of DNA from fossil material. They also pursued historical and biological questions about the organisms and populations under investigation. However, I have determined that these researchers have adopted a further research strategy: *celebrity-driven science*. In this history, scientists capitalized on publicity opportunities and created their own opportunities for attention too in order to communicate the excitement as well as value of this new line of research to professional, public, and political audiences. In other words, this history of the search for DNA from fossils has highlighted how celebrity can drive and direct scientific or technological research like data collecting and hypothesis testing can.

Ancient DNA is an especially interesting case study for the philosophy of science because it emerged from the interface of disparate disciplines with distinctive research traditions and different epistemic standards. This is important to note because the search for DNA from fossils brought together practitioners from paleontology and archeology (i.e. more historical sciences) with researchers from molecular biology and genetics (i.e. more experimental sciences). Consequently, the individuals involved in ancient DNA research had to create their own scientific and epistemic culture. Celebrity played a part in this.

Specifically, there were two ways in which the celebrity of the practice had a hand in ancient DNA's growth from the 1980s to today in terms of influencing the community's formation and identity over a thirty-year-period. Although celebrity destabilized that practice during a credibility crisis, the steady stream of press and public recognition also helped to define the search for DNA from fossils as a practice in its own right. In the absence of an overarching theoretical framework, as well as in the absence of, or difficulty in obtaining consistent financial or institutional support for research in its early years, celebrity gave the field and the scientists within it some sort of legitimacy. To be clear, celebrity in the form of extreme media exposure gave definition and direction to ancient DNA research in its earliest and most vulnerable phase of development. Here, branding was far from superficial. It was purposeful and pragmatic. Scientists used this consistent attention to help shape ancient DNA activity in terms of influencing the questions they asked, the funding they received, and the way they have framed their research when communicating to wider popular and political audiences about its significance.

Although researchers draw on celebrity as a serious epistemic strategy, some scientists still put it down as not being a respectable scientific approach. Indeed, some scientists insist on hypothesis testing as proper scientific practice but also argue that not all hypotheses are created equal. Specifically, they tend to put down research projects that test hypotheses likely to attract media headlines. In a 2004 article, Pääbo (a scientifically and politically powerful player in the field) and coauthors reminded readers of ancient DNA's short but sensational history. They further noted that the practice still had a tendency to draw media headlines: "The study of ancient DNA has the allure of time travel and attracts much attention and many practitioners" (Pääbo et al. 2004, 661). In light of its popularity, Pääbo and coauthors argued that researchers should adhere to proper research protocols and that such studies ought to be focused on trying to answer scientifically significant questions: "The first prerequisite of any ancient DNA project should be a clear understanding of the biological question at hand and how analysis of ancient DNA is an essential aspect of addressing the question." To put this point into perspective, they cited a series of studies they thought favored popular interest over scientific importance: "Other projects such as ancient DNA analyses of public personalities such as Christopher Columbus, Jesse James, or former U.S. presidents may be novel and of interest to the public. However, they are devoid of any larger scientific contribution and sometimes ethically questionable" (Pääbo et al. 2004, 670). This article, published in 2004 and nearly two decades following the birth of the field, demonstrated the professional perception that ancient DNA's populist past was far from forgotten. For Pääbo and coauthors, having a hypothesis was not enough to make a research project a good project. For these scientists, hypotheses fell into a hierarchy and those projects with hypotheses that favored popular interest over research relevance fell last in line. In this case, researchers both recognized but also condemned the celebrity-driven aspect of these studies. Although a philosopher would recognize that research questions come in different forms, some scientists felt that some questions or hypotheses were better, and therefore more legitimate, than others. In other words, they felt that this celebrity-driven strategy was in direct conflict, or at least in tension, with hypothesis-driven research.

This presumed distinction between data-driven and hypothesis-driven science has often been discussed in relationship to the concept of prestige. Traditionally, scientists have argued that hypothesis-driven research is more scientific, and therefore more prestigious, than data-driven research. Indeed, the latter has often been equated to stamp-collecting or what scientists see as lower-levels of gathering and organizing information (Kell and Oliver 2004; Glass and Hall 2008; Weinberg 2010; Elliott et al. 2016). In its most extreme form, exploratory or data-driven research has even been equated to "fishing expeditions" or "scientific malpractice" (Kell and Oliver 2004; Hjortrup et al. 2016). This idea of prestige is important for celebrity-driven science too. Based on interviews and comments in the literature, as evidenced in this article, some scientists seem to think that celebrity undermines prestige. This is not unique to ancient DNA research given that other historians and philosophers have discussed the assumed effect that publicity can have on prestige in both the natural and physical sciences.[22] Although this may at times be the

[22] Derek Turner, for example, spotlighted the positive and negative effects that publicity can have on the science of paleontology. Here, Turner noted the disproportionate attention directed towards organismic reconstruction in general, and dinosaur paleontology in specific, while evolutionary paleontology with its much more theoretical nature remained lesser known to popular audiences (2011, 10). According to Turner, some scientists often feel that too much attention, or a disproportionate amount of attention, can distort the public perception of relevant scientific research. This issue of publicity and prestige extends to the physical sciences as well. Joseph Martin noted that in the field of physics, areas such as high energy physics and cosmology often received more public attention than other areas like solid state and condensed matter physics. Martin argues that this is interesting given that the majority of research in physics is dedicated to work in solid state and condensed matter physics. Martin called this a "*prestige asymmetry*" in which similar activities receive unequal attention and admiration (Martin 2017).

case, this history of ancient DNA research has demonstrated that celebrity has actually been foundational to the birth and growth of this practice and has been further used to actually establish prestige. The role of celebrity, and scientists' aptitude to recognize and utilize it to their benefit, should not be underestimated. Rather, celebrity can be valuable to the process and practice of science, particularly in the early years of scientific or technological innovation. This particular point has wider implications when considering the effect that public profile has on science in terms of influencing the questions researchers ask, the funding they receive, and how they frame their research when communicating to wider popular or political audiences about its significance.[23]

Conclusion

In this article, I argued that the search for DNA from fossils, throughout its thirty-year history from the 1980s to today, can be characterized as an example of a data-driven and celebrity-driven practice. Facilitated by the new use of innovations from PCR to NGS, scientists were very much driven by data in terms of samples, technology, and the molecular information (DNA) that can be recovered from accessible samples using existing technologies. At the

[23] As a work in the history of science, I am aware that this paper has not explored the social context in which the search for DNA from fossils emerged then evolved. It has also not explained the context or causes that might be responsible for such a celebrity-driven approach in the first place. I want to make a few points in reference to part of my work that I have intentionally neglected in this paper. First, researchers today do not solely seek celebrity for their five minutes of fame; they seek it because there is an expectation for them to popularize their research to the public through the press. The modern science communication movement of the 1980s, initiated in the UK but influential in the US and elsewhere, along with other developments towards the "mediatization," "medialization," and "celebrification" of science have set the stage for these expectations and for the intense interplay between science and media (Nelkin 1995; Gregory and Miller 1998; Evans and Hesmondhalgh 2005; Broks 2006; Radder 2010; Rödder, Franzen, and Weingart 2012; Bucchi and Trench 2014). Decisions regarding funding and employment are often evaluated with an eye towards impact, outreach, and publicity. Indeed, news value affects more than science reporting; it also affects how and what science gets published. By extension, it also affects an individual's or a group's success within science. One interviewee described this as a self-perpetuating system, where newsworthy studies that make high-profile publications lead to high-profile press, which leads to further funding (25-01:21:45). According to some scientists, this system has created a sort of scientist skilled in packaging their research to both scientific journals and journalists. The result is a media-savvy scientist (but not perhaps a celebrity science in Fahy's sense or even a visible scientist according to Goodell's analysis) who has learned the language of the press, including differences between scientific and journalistic expectations and practices when it comes to reporting research. In the history of ancient DNA research, we see that researchers are responding to the call to communicate and that their position in the spotlight gives them opportunities to do so. In tracing the evolution of practice like ancient DNA research, its evolution into a celebrity-driven science captures the consequences of the ever-closer connection between science and media, including its influences on the practice of science and science communication. An analysis of the causes and consequences of celebrity-driven science cannot be fully discussed in this article but will be covered at a different time. See Jones (2017) for an initial discussion of these ideas.

same time, however, this practice was very much a celebrity-driven one. Here, intense press and public interest, thanks to the book and movie *Jurassic Park*, had a hand in ancient DNA's emergence then evolution into a practice in terms of its formation and community identity. Indeed, I argued that celebrity can actually influence the process and practice of science over a prolonged period of time in terms of its impact on research agendas, publication timing, grant funding, and popular perceptions of the search for DNA from fossils.

Today, in the recent era of high-throughput sequencing technologies, philosophers have suggested the need to take seriously the role of data-driven inquiry in the sciences. Likewise, this history of ancient DNA research has suggested the need to take seriously the role of celebrity-driven inquiry in shaping the kind of research that gets pursued, funded, and ultimately completed. On this point, this history has highlighted that the traditional philosophical and scientific distinctions between data-driven and hypothesis-driven research are not always useful for understanding the process or practice of science, and that the celebrity status of a particular research practice can also be considered as a "serious epistemic strategy" that researchers, as well as editors and funders, employ when making choices about their research and publication practices. By considering celebrity, we can be better equipped to explore the effect that public profile has on research and how the philosophy of science might in turn be better informed by it.

REFERENCES

Allentoft, Morten E., Martin Sikora, Karl-Göran Sjögren, Simon Rasmussen, Morten Rasmussen, Jesper Stenderup, Peter B. Damgaard, et al. 2015. "Population Genomics of Bronze Age Eurasia." *Nature* 522 (7555): 167–72.

"Ancient DNA: The First Three Decades." 2013. The Royal Society, London.

"Ancient DNA: The Recovery and Analysis of DNA Sequences from Archaeological Material and Museum Specimens." 1991. Nottingham, England. Elizabeth Jones Personal Collection (File from Richard Thomas).

Atkinson, Rowland, and John Flint. 2001. "Accessing Hidden and Hard-to-Reach Populations: Snowball Research Strategies." *Social Research Update* 33.

Austin, Jeremy J, Andrew J Ross, Andrew B Smith, Richard A Fortey, and Richard H Thomas. 1997. "Problems of Reproducibility – Does Geologically Ancient DNA Survive in Amber-Preserved Insects?" *Proceedings of the Royal Society, Series B, Biological Sciences* 264 (1381): 467–74.

Benton, Mike. 1985. "To Clone a Dinosaur." *New Scientist*, January 17.

Bollongino, R, C J Edwards, K W Alt, J Burger, and D G Bradley. 2006. "Early History of European Domestic Cattle as Revealed by Ancient DNA." *Biology Letters* 2 (1): 155–59.

Bos, Kirsten I, Verena J Schuenemann, G Brian Golding, Hernán A Burbano, Nicholas Waglechner, Brian K Coombes, Joseph B McPhee, et al. 2011. "A Draft Genome of Yersinia Pestis from Victims of the Black Death." *Nature* 478 (7370): 506–10.

Bösl, Elsbeth. 2017a. *Doing Ancient DNA: Zur Wissenschaftsgeschichte Der aDNA-Forschung*. Bielefeld: Verlag.

———. 2017b. "Zur Wissenschaftsgeschichte Der aDNA-Forschung." *NTM Zeitschrift Für Geschichte Der Wissenschaften, Technik Und Medizin* 25 (1): 99–142.

Bramanti, B, M G Thomas, W Haak, M Unterlaender, P Jores, K Tambets, I Antanaitis-Jacobs, et al. 2009. "Genetic Discontinuity Between Local Hunter-Gatherers and Central Europe's First Farmers." *Science* 326 (5949): 137–40.

Broks, Peter. 2006. *Understanding Popular Science*. Maidenhead: Open University Press.

Browne, Malcolm W. 1991. "Scientists Study Ancient DNA for Glimpses of Past Worlds." *The New York Times*, June 25.

———. 1993a. "DNA From the Age of Dinosaurs Is Found." *The New York Times*, June 10. http://www.nytimes.com/1993/06/10/us/dna-from-the-age-of-dinosaurs-is-found.html.

———. 1993b. "Cells of Dinosaurs Apparently Found." *The New York Times*, July 1. http://www.nytimes.com/1993/07/01/us/cells-of-dinosaur-apparently-found.html.

Bucchi, Massimiano, and Brian Trench. 2014. *Routledge Handbook of Public Communication of Science and Technology: Second Edition*. Abingdon: Routledge.

Burger, J, M Kirchner, B Bramanti, W Haak, and M G Thomas. 2007. “Absence of the Lactase-Persistence-Associated Allele in Early Neolithic Europeans.” *Proceedings of the National Academy of Sciences of the United States of America* 104 (10): 3736–41.

Callaway, Ewen. 2015a. “DNA Data Explosion Lights up the Bronze Age.” *Nature* 522 (7555): 140–41.

———. 2015b. “Genome Archaeologist.” *Nature* 528: 464–65.

———. 2018. “Divided by DNA: The Uneasy Relationship between Archaeology and Ancient Genomics.” *Nature* 555 (7698): 573–76.

Callebaut, Wener. 2012. “Scientific Perspectivism: A Philosopher of Science’s Response to the Challenge of Big Data Biology.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 43 (1): 69–80.

Calvert, Jane. 2012. “Systems Biology, Synthetic Biology and Data-Driven Research: A Commentary on Krohs, Callebaut, and O’Malley and Soyer.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 43 (1): 81–84.

Cano, Raul J, Hendrik N Poinar, Norman J Pieniazek, Aftim Acra, and George O Poinar Jr. 1993. “Amplification and Sequencing of DNA from a 120-135-Million-Year-Old Weevil.” *Nature* 363: 536–38.

Cano, Raúl J, Hendrik N Poinar, Norman J Pieniazek, Aftim Acra, and George O Poinar Jr. 1993. “Amplification and Sequencing of DNA from a 120–135-Million-Year-Old Weevil.” *Nature* 363 (6429): 536–38.

Cano, Raúl J, Hendrik N Poinar, and George O Poinar Jr. 1992. “Isolation and Partial Characterisation of DNA from the Bee Proplebeia Dominicana (Apidae: Hymenoptera) in 25–40 Million Year Old.” *Medical Science Research* 20 (7): 249–251.

Chapman, Robert, and Alison Wylie. 2016. *Evidential Reasoning in Archaeology*. London: Bloomsbury Publishing.

Clifton, Lewis. 1984. “Mad Scientists Are Cloning Dinosaurs as Weapons of the Future.” *National Examiner*, August 7. Elizabeth Jones Personal Collection (File from Russell Higuchi).

Cooper, Alan. 2006. “The Year of the Mammoth.” *PLoS Biology* 4 (3): 0311–13.

Cooper, Alan, and Hendrik N Poinar. 2000. “Ancient DNA: Do It Right or Not at All.” *Science* 289 (5482): 1139.

Currie, Adrian. 2018. *Rock, Bone, and Ruin: An Optimist’s Guide to the Historical Sciences*. Cambridge, Massachusetts: MIT Press.

Currie, Adrian, and Kim Sterelny. 2017. "In Defence of Story-Telling." *Studies in History and Philosophy of Biological and Biomedical Sciences* 62: 14–21.

Der Sarkissian, Clio, Morten E Allentoft, María C Avila-Arcos, Ross Barnett, Paula F Campos, Enrico Cappellini, Luca Ermini, et al. 2015. "Ancient Genomics." *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences* 370 (1660): 1–12.

DeSalle, Rob, John Gatesy, Ward Wheeler, and David Grimaldi. 1992. "DNA Sequences from a Fossil Termite in Oligo-Miocene Amber and Their Phylogenetic Implications." *Science* 257 (5078): 1933–36.

DeSalle, Rob, and David Lindley. 1997. *The Science of Jurassic Park and The Lost World or How to Build a Dinosaur*. New York: Basic Books.

Elliott, Kevin C, Kendra S Cheruvelil, Georgina M Montgomery, and Patricia A Soranno. 2016. "Conceptions of Good Science in Our Data-Rich World." *BioScience* 66 (10): 1–10.

Evans, Jessica, and David Hesmondhalgh. 2005. *Understanding Media: Inside Celebrity*. Maidenhead: Open University Press.

Fahy, Declan. 2015. *The New Celebrity Scientists: Out of the Lab and into the Limelight*. Lanham: Rowman and Littlefield.

Feyerabend, P. 1975. *Against Method*. London: New Left Books.

Freedman, J, L van Dorp, and S Brace. 2017. "Destructive Sampling Natural Science Collections: An Overview for Museum Professionals and Researchers." *Journal of Natural Science Collections* 5: 1–14.

Gibbons, Ann. 1994. "Possible Dino DNA Greeted with Skepticism." *Science* 266: 1159.

———. 2012. "A Crystal-Clear View of an Extinct Girl's Genome." *Science* 337 (August): 1028–29.

Gieryn, Thomas F. 1983. "Boundary-Work and the Demarcation of Science from Non-Science: Strains and Interests in Professional Ideologies of Scientists." *American Sociological Review* 48 (6): 781–95.

———. 1999. *Cultural Boundaries of Science: Credibility on the Line*. Chicago: Univeristy of Chicago Press.

Gilbert, M Thomas P, Hans Jürgen Bandelt, Michael Hofreiter, and Ian Barnes. 2005. "Assessing Ancient DNA Studies." *Trends in Ecology and Evolution* 20 (10): 541–44.

Gilbert, M Thomas P, Daniela I Drautz, Arthur M Lesk, Simon Y W Ho, Ji Qi, Aakrosh Ratan, Chih-Hao Hsu, et al. 2008. "Intraspecific Phylogenetic Analysis of Siberian Woolly Mammoths Using Complete Mitochondrial Genomes." *Proceedings of the National Academy of Sciences of the United States of America* 105 (24): 8327–32.

Gilbert, M Thomas P, Toomas Kivisild, Bjarne Grønnow, Pernille K Andersen, Ene Metspalu, Maere Reidla, Erika Tamm, et al. 2008. "Paleo-Eskimo mtDNA Genome Reveals Matrilineal Discontinuity in Greenland." *Science* 320 (5884): 1787–89.

Glass, David J, and Ned Hall. 2008. "A Brief History of the Hypothesis." *Cell* 134 (3): 378–81.

Gokhman, D, E Lavi, K Prufer, M F Fraga, J A Riancho, J Kelso, S Paabo, E Meshorer, and L Carmel. 2014. "Reconstructing the DNA Methylation Maps of the Neandertal and the Denisovan." *Science* 344 (6183): 523–27.

Golenberg, Edward M, David E Giannasi, Michael T Clegg, Charles J Smiley, Mary Durbin, David Henderson, and Gerard Zurawski. 1990. "Chloroplast DNA Sequence from a Miocene Magnolia Species." *Nature* 344: 656–58.

Goodell, Rae. 1975. *The Visible Scientists*. Boston: Little, Brown and Company.

Gould, Stephen Jay. 1996. "Dinomania." In *Dinosaur in a Haystack: Reflections in Natural History*, 221–37. London: Jonathan Cape.

Graves, Gary R, and Michael J Braun. 1992. "Museums: Storehouse of DNA?" *Science* 255 (5050): 1335–36.

Green, Richard E, Johannes Krause, Adrian W Briggs, Tomislav Maricic, Udo Stenzel, Martin Kircher, Nick Patterson, et al. 2010. "A Draft Sequence of the Neandertal Genome." *Science* 328 (5979): 710–22.

Gregory, Jane, and Steve Miller. 1998. *Science in Public: Communication, Culture, and Credibility*. Cambridge, Massachusetts: Basic Books.

Haak, Wolfgang, Oleg Balanovsky, Juan J. Sanchez, Sergey Koshel, Valery Zaporozhchenko, Christina J. Adler, Clio S. I. Der Sarkissian, et al. 2010. "Ancient DNA from European Early Neolithic Farmers Reveals Their Near Eastern Affinities." *PLoS Biology* 8 (11): 1–16.

Haak, Wolfgang, Peter Forster, Barbara Bramanti, Shuichi Matsumura, Guido Brandt, Marc Tänzer, Richard Villems, et al. 2005. "Ancient DNA from the First European Farmers in 7500-Year-Old Neolithic Sites." *Science* 310 (5750): 1016–18.

Hagelberg, Erika, Michael Hofreiter, and Christine Keyser. 2015. "Introduction. Ancient DNA: The First Three Decades." *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences* 370 (1660): 1–6.

Handt, Oliva, Martin Richards, Marion Trommsdorff, Christian Kilger, Jaana Simanainen, Oleg Georgiev, Karin Bauer, et al. 1994. "Molecular Genetic Analyses of the Tyrolean Ice Man." *Science* 264 (5166): 1775–78.

Haufe, Chris. 2013. "Why Do Funding Agencies Favor Hypothesis Testing?" *Studies in History and Philosophy of Science* 44: 363–74.

Hebsgaard, Martin B, Matthew J Phillips, and Eske Willerslev. 2005. “Geologically Ancient DNA: Fact or Artefact?” *Trends in Microbiology* 13 (5): 212–20.

Hedges, S. Blair, and M. Schweitzer. 1995. “Detecting Dinosaur DNA.” *Science* 268 (5214): 1191–92.

Higuchi, R, B Bowman, M Freiberger, O A Ryder, and A C Wilson. 1984. “DNA Sequences from the Quagga, an Extinct Member of the Horse Family.” *Nature* 312: 282–84.

Hjortrup, Peter B, Nicolai Haase, Jørn Wetterslev, and Anders Perner. 2016. “Gone Fishing in a Fluid Trial.” *Critical Care and Resuscitation: Journal of the Australasian Academy of Critical Care Medicine* 18 (1): 55–58.

Horner, John R, and Ernst Vyse. 1993. “An Attempt to Extract DNA from the Cretaceous DinosaurTyrannosaurus Rex.” *National Science Foundation*. https://www.nsf.gov/awardsearch/showAward?AWD_ID=9311542.

Ion, Alexandra. 2017. “How Interdisciplinary Is Interdisciplinary? Revisiting the Impact of aDNA Research for the Archaeology of Human Remains.” *Current Swedish Archaeology* 25: 87–108.

Itan, Yuval, Adam Powell, Mark A Beaumont, Joachim Burger, and Mark G Thomas. 2009. “The Origins of Lactase Persistence in Europe.” *PLoS Computational Biology* 5 (8): 17–19.

Izagirre, N, and C de la Rúa. 1999. “An mtDNA Analysis in Ancient Basque Populations: Implications for Haplogroup V as a Marker for a Major Paleolithic Expansion from Southwestern Europe.” *American Journal of Human Genetics* 65 (1): 199–207.

Jeffreys, Alec J. 1984. “Raising the Dead and Buried.” *Nature* 312: 198.

Jones, Bryony Leigh, Tamiru Oljira, Anke Liebert, Pawel Zmarz, Nicolas Montalva, Ayele Tarekeyn, Rosemary Ekong, et al. 2015. “Diversity of Lactase Persistence in African Milk Drinkers.” *Human Genetics* 134 (8): 917–25.

Jones, Elizabeth. 2017. “The Search for Ancient DNA in the Media Limelight: A Case Study of Celebrity Science.” PhD Thesis. University College London.

Jones, Elizabeth D. 2018. “Ancient DNA: a history of the science before Jurassic Park.” *Studies in History and Philosophy of Biological and Biomedical Sciences*. 68-69: 1-14.

“Jurassic Park (1993).” 2017. *IMDb*. Accessed February 1. http://www.imdb.com/title/tt0107290/.

Keating, Peter, and Alberto Cambrosio. 2012. “Too Many Numbers: Microarrays in Clinical Cancer Research.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 43 (1): 37–51.

Kell, D B, and S G Oliver. 2004. “Here Is the Evidence, Now What Is the Hypothesis? The Complementary Roles of Inductive and Hypothesis-Driven Science in the Post-Genomic Era.” *BioEssays* 26 (1): 99–105.

Kell, Douglas B., and Stephen G. Oliver. 2004. “Here Is the Evidence, Now What Is the Hypothesis? The Complementary Roles of Inductive and Hypothesis-Driven Science in the Post-Genomic Era.” *BioEssays* 26 (1): 99–105.

King, Peter H. 1993. “‘Step Right Up and See the Science.’” *Los Angeles Times*, June 16. http://articles.latimes.com/1993-06-16/news/mn-3654_1_dna-research.

King, Turi E., Gloria Gonzalez Fortes, Patricia Balaresque, Mark G. Thomas, David Balding, Pierpaolo Maisano Delser, Rita Neumann, et al. 2014. “Identification of the Remains of King Richard III.” *Nature Communications* 5 (December): 5631.

Kirby, D. a. 2003. “Science Consultants, Fictional Films, and Scientific Practice.” *Social Studies of Science* 33 (2): 231–68.

Kirby, David. 2014. “Science and Technology in Film: Themes and Representations.” In *Routledge Handbook of Public Communication of Science and Technology*, edited by Massimiano Bucchi and Brian Trench. Abingdon: Taylor and Francis.

Kirby, David A. 2013. *Lab Coats in Hollywood: Science, Scientists, and Cinema*. Cambridge, Massachusetts: MIT Press.

Kirby, David a. 2003. “Scientists on the Set: Science Consultants and the Communication of Science in Visual Fiction.” *Public Understanding of Science* 12: 261–78.

Knapp, Michael, and Michael Hofreiter. 2010. “Next Generation Sequencing of Ancient DNA: Requirements, Strategies and Perspectives.” *Genes* 1 (2): 227–43.

Krause, Johannes, Qiaomei Fu, Jeffrey M Good, Bence Viola, Michael V Shunkov, Anatoli P Derevianko, and Svante Pääbo. 2010. “The Complete Mitochondrial DNA Genome of an Unknown Hominin from Southern Siberia.” *Nature* 464 (7290). Macmillan Publishers Limited. All rights reserved: 894–97.

Krohs, Ulrich. 2012. “Convenience Experimentation.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 43 (1): 52–57.

Kuhn, Thomas. 1962. *The Structure of Scientific Revolutions*. Chicago: Univeristy of Chicago Press.

Lakatos, Imre. 1970. “Falsification and the Methodology of Research Program.” In *Criticism and the Growth of Knowledge*, edited by Imre Lakatos and Alan Musgrave, 91–197. Cambridge, England: Cambridge University Press.

Larson, Greger, Umberto Albarella, Keith Dobney, Peter Rowley-Conwy, Jörg Schibler, Anne Tresset, Jean-Denis Vigne, et al. 2007. “Ancient DNA, Pig Domestication, and the Spread of the Neolithic into Europe.” *Proceedings of the National Academy of Sciences of the United States of America* 104 (39): 15276–81.

Larson, Greger, Elinor K Karlsson, Angela Perri, Matthew T Webster, Simon Y W Ho, Joris Peters, Peter W Stahl, et al. 2012. "Rethinking Dog Domestication by Integrating Genetics, Archeology, and Biogeography." *Proceedings of the National Academy of Sciences of the United States of America* 109 (23): 8878–83.

Larson, Greger, Dolores R Piperno, Robin G Allaby, Michael D Purugganan, Leif Andersson, Manuel Arroyo-Kalin, Loukas Barton, et al. 2014. "Current Perspectives and the Future of Domestication Studies." *Proceedings of the National Academy of Sciences of the United States of America* 111 (17): 6139–46.

Laudan, Larry. 1981. *Science and Hypothesis: Historical Essays on Scientific Methodology*. London: Reidel.

Leonard, J A, Robert K Wayne, Jane Wheeler, Raúl Valadez, Sonia Guillén, and Carles Vilà. 2002. "Ancient DNA Evidence for Old World Origin of New World Dogs." *Science* 298 (5598): 1613–16.

Leonelli, S. 2012. "Introduction: Making Sense of Data-Driven Research in the Biological and Biomedical Sciences." *Studies in History and Philosophy of Biological and Biomedical Sciences* 43 (1): 1–3.

Leonelli, Sabina. 2016. *Data-Centric Biology: A Philosophical Study*. Chicago: Univeristy of Chicago Press.

Leonelli, Sabina, and Rachel A Ankeny. 2012. "Re-Thinking Organisms: The Impact of Databases on Model Organism Biology." *Studies in History and Philosophy of Biological and Biomedical Sciences* 43 (1): 29–36.

Lindahl, T. 1993a. "Instability and Decay of the Primary Structure of DNA." *Nature* 362: 709–15.

———. 1993b. "Recovery of Antediluvian DNA." *Nature* 365 (6448): 700.

Lister, A M. 1994. "Ancient DNA: Not Quite Jurassic Park." *Trends in Ecology and Evolution* 9 (3): 82–4.

Macintyre, B. 1993. "Fossil Find Brings Jurassic Park Closer." *The Times*, July 2.

Malmström, Helena, Anna Linderholm, Pontus Skoglund, Jan Storå, Per Sjödin, M Thomas P Gilbert, Gunilla Holmlund, et al. 2015. "Ancient Mitochondrial DNA from the Northern Fringe of the Neolithic Farming Expansion in Europe Sheds Light on the Dispersion Process." *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 370 (1660): 1–10.

Margulies, Marcel, Michael Egholm, William E Altman, Said Attiya, Joel S Bader, Lisa A Bemben, Jan Berka, et al. 2005. "Genome Sequencing in Microfabricated High-Density Picolitre Reactors." *Nature* 437 (September): 376–80.

Martin, Joseph. 2017. "Prestige Asymmetry in American Physics: Aspirations, Applications, and the Purloined Letter Effect." *Science in Context* 30 (4).

Mathieson, Iain, Songül Alpaslan-Roodenberg, Cosimo Posth, Anna Szécsényi-Nagy, Nadin Rohland, Swapan Mallick, Iñigo Olalde, et al. 2018. "The Genomic History of Southeastern Europe." *Nature* 555 (7695): 197–203.

Miller, Webb, Daniela I Drautz, Aakrosh Ratan, Barbara Pusey, Ji Qi, Arthur M Lesk, Lynn P Tomsho, et al. 2008. “Sequencing the Nuclear Genome of the Extinct Woolly Mammoth.” *Nature* 456 (7220): 387–90.

“Molecular Paleontology: Search for Fossil DNA.” 1984. National Science Foundation Grant. Elizabeth Jones Personal Collection (File from Russeull Higuchi).

Morell, Virginia. 1993. “Dino DNA: The Hunt and the Hype.” *Science* 261 (5118): 160–62.

Muller-Wille, Staffan, and Isabelle Charmantier. 2012. “Natural History and Information Overload: The Case of Linnaeus.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 43 (1): 4–15.

Mullis, Kary B, and Fred A Faloona. 1987. “Specific Synthesis of DNA in Vitro via a Polymerase-Catalyzed Chain Reaction.” *Methods in Enzymology* 155: 335–50.

Nelkin, Dorothy. 1995. *Selling Science: How the Press Covers Science and Technology*. New York: W. H. Freeman and Company.

Olalde, Iñigo, Selina Brace, Morten E. Allentoft, Ian Armit, Kristian Kristiansen, Thomas Booth, Nadin Rohland, et al. 2018. “The Beaker Phenomenon and the Genomic Transformation of Northwest Europe.” *Nature* 555 (7695): 190–96.

O’Malley, Maureen A. 2007. “Exploratory Experimentation and Scientific Practice: Metagenomics and the Proteorhodopsin Case.” *History and Philosophy of the Life Sciences* 29 (3): 337–60.

O’Malley, Maureen A, Kevin C Elliott, Chris Haufe, and Richard M Burian. 2009. “Philosophies of Funding.” *Cell* 138 (4): 611–15.

O’Malley, Maureen A, and Orkun S Soyer. 2012. “The Roles of Integration in Molecular Systems Biology.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 43 (1): 58–68.

Pääbo, Svante, Russell G Higuchi, and Allan C Wilson. 1989. “Ancient DNA and the Polymerase Chain Reaction.” *The Journal of Biological Chemistry* 264 (17): 9709–12.

Pääbo, Svante, Hendrik Poinar, David Serre, Viviane Jaenicke-Després, Juliane Hebler, Nadin Rohland, Melanie Kuch, Johannes Krause, Linda Vigilant, and Michael Hofreiter. 2004. “Genetic Analyses from Ancient DNA.” *Annual Review of Genetics* 38 (1): 645–79.

Pedersen, Jakob Skou, Eivind Valen, Amhed M Vargas Velazquez, Brian J Parker, Morten Rasmussen, Stinus Lindgreen, Berit Lilje, et al. 2014. “Genome-Wide Nucleosome Map and Cytosine Methylation Levels of an Ancient Human Genome.” *Genome Research* 24 (3): 454–66.

Pellegrino, Charles. 1985. "Dinosaur Capsule." *Omni* 7: 38-40-115.

Poinar, Hendrik N, Carsten Schwarz, Ji Qi, Beth Shapiro, Ross D E Macphee, Bernard Buigues, Alexei Tikhonov, et al. 2006. "Metagenomics to Paleogenomics: Large-Scale Sequencing of Mammoth DNA." *Science* 311 (2006): 392–94.

Poinar Jr, George O, Hendrik N Poinar, and Raul J Cano. 1994. "DNA from Amber Inclusions." In *Ancient DNA: Recovery and Analysis of Genetic Material from Paleontological, Archaeological, Museum, Medical, and Forensic Specimens*, edited by Bernd Herrmann and Susanne Hummel, 92–103. New York: Springer-Verlag.

Poinar Jr, George O, and Roberta Poinar. 1994. *The Quest for Life in Amber*. Cambridge, Massachusetts: Perseus Publishing.

Popper, Karl. 1959. *The Logic of Scientific Discovery*. London: Routledge.

Rabinow, Paul. 1996. *Making PCR: A Story of Biotechnology*. Chicago: University of Chicago Press.

Radder, Hans. 2010. *The Commodification of Academic Research: Science and the Modern University*. Pittsburgh: University of Pittsburgh Press.

Rasmussen, Morten, Sarah L Anzick, Michael R Waters, Pontus Skoglund, Michael DeGiorgio, Thomas W Stafford, Simon Rasmussen, et al. 2014. "The Genome of a Late Pleistocene Human from a Clovis Burial Site in Western Montana." *Nature* 506 (7487): 225–29.

Rasmussen, Morten, Xiaosen Guo, Yong Wang, Kirk E Lohmueller, Simon Rasmussen, Anders Albrechtsen, Line Skotte, et al. 2011. "An Aboriginal Australian Genome Reveals Separate Human Dispersals into Asia." *Science* 334 (6052): 94–98.

Rasmussen, Morten, Yingrui Li, Stinus Lindgreen, Jakob Skou Pedersen, Anders Albrechtsen, Ida Moltke, Mait Metspalu, et al. 2010. "Ancient Human Genome Sequence of an Extinct Palaeo-Eskimo." *Nature* 463 (7282): 757–62.

Reich, David. 2018. *Who We Are and How We Got Here: Ancient DNA and the New Science of the Human Past*. New York: Pantheon Books.

Reich, David, Richard E Green, Martin Kircher, Johannes Krause, Nick Patterson, Eric Y Durand, Bence Viola, et al. 2010. "Genetic History of an Archaic Hominin Group from Denisova Cave in Siberia." *Nature* 468 (7327). Nature Publishing Group: 1053–60.

Rensberger, Boyce. 1992. "Entombed in Amber, Ancient DNA Hints of 'Jurassic Park.'" *The Washington Post*, September 25. https://www.washingtonpost.com/archive/politics/1992/09/25/entombed-in-amber-ancient-dna-hints-of-jurassic-park/7309d11f-8d62-4589-ba8e-a493392dc6e9/.

Rödder, Simone, Martina Franzen, and Peter Weingart, eds. 2012. *The Sciences' Media Connection -Public Communication and Its Repercussions*. Dordrecht: Springer.

Rojek, Chris. 2001. *Celebrity*. London: Reaktion Books.

Scheu, Amelie, Sönke Hartz, Ulrich Schmolcke, Anne Tresset, Jaochim Burger, and Ruth Bollongino. 2008. "Ancient DNA Provides No Evidence for Independent Domestication of Cattle in Mesolithic Rosenhof, Northern Germany." *Journal of Archaeological Science* 35 (5): 1257–1264.

Service, Robert F. 1996. "Just How Old Is That DNA, Anyway?" *Science* 272 (5263): 810.

Shapiro, Beth. 2015. *How to Clone a Mammoth: The Science of De-Extinction*. Princeton: Princeton University Press.

Skoglund, Pontus, Erik Ersmark, Eleftheria Palkopoulou, and Love Dalén. 2015. "Ancient Wolf Genome Reveals an Early Divergence of Domestic Dog Ancestors and Admixture into High-Latitude Breeds." *Current Biology* 25: 1–5.

Skoglund, Pontus, Helena Malmström, Maanasa Raghavan, Jan Storå, Per Hall, Eske Willerslev, M Thomas P Gilbert, Anders Götherström, and Mattias Jakobsson. 2012. "Origins and Genetic Legacy of Neolithic Farmers and Hunter-Gatherers in Europe." *Science* 336 (6080): 466–69.

Stoneking, Mark, and Johannes Krause. 2011. "Learning about Human Population History from Ancient and Modern Genomes." *Nature Reviews Genetics* 12 (9): 603–14.

Strasser, Bruno J. 2012. "Data-Driven Sciences: From Wonder Cabinets to Electronic Databases." *Studies in History and Philosophy of Biological and Biomedical Sciences* 43: 85–87.

Stringer, Chris. 2012. *Lone Survivors: How We Came to Be the Only Humans on Earth*. New York: St. Martin's Press.

Tkach, John R. 1983. "The Extinct DNA Newsletter." Elizabeth Jones Personal Collection (File from John Tkach).

Turner, Derek. 2011. *Paleontology: A Philosophical Introduction*. Cambridge, England: Cambridge University Press.

Turner, Graeme. 2004. *Understanding Celebrity*. London: SAGE Publications.

Veeramah, Krishna R, and Michael F Hammer. 2014. "The Impact of Whole-Genome Sequencing on the Reconstruction of Human Population History." *Nature Reviews* 15: 149–62.

Warinner, C, J Hendy, C Speller, E Cappellini, R Fischer, C Trachsel, J Arneborg, et al. 2014. "Direct Evidence of Milk Consumption from Ancient Human Dental Calculus." *Scientific Reports* 4 (7104): 1–6.

Wayne, Robert, and Alan Cooper, eds. 1992. "Ancient DNA Newsletter" 1 (2). London, England: Institute of Zoology: 1–41. Elizabeth Jones Personal Collection (Files from Richard Thomas and Terry Brown).

Weinberg, Robert. 2010. "Point: Hypotheses First." *Nature* 464 (7289): 678–678.

Willerslev, Eske, John Davison, Mari Moora, Martin Zobel, Eric Coissac, Mary E Edwards, Eline D Lorenzen, et al. 2014. "Fifty Thousand Years of Arctic Vegetation and Megafaunal Diet." *Nature* 506 (7486): 47–51.

Willerslev, Eske, Anders J Hansen, and Hendrik N Poinar. 2004. "Isolation of Nucleic Acids and Cultures from Fossil Ice and Permafrost." *Trends in Ecology and Evolutionology and Evolution* 19 (3): 140–47.

Woodward, Scott R, Nathan J Weyand, and Mark Bunnell. 1994. "DNA Sequence from Cretaceous Period Bone Fragments." *Science* 266 (5188): 1229–32.

Wray, Britt. 2017. *Rise of the Necrofauna: A Provocative Look at the Science, Ethics, and Risks of De-Extinction*. Vancouver, British Columbia: Greystone Books.

Zischler, H, M Höss, O Handt, A von Haeseler, A C van der Kuyl, J Goudsmit, and S Pääbo. 1995. "Detecting Dinosaur DNA." *Science* 268 (5214): 1192–93.