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Narrative and "Anti-narrative" in Science: How Scientists Tell Stories, and Don't

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Synopsis Narratives are common to all branches of science, not only to the humanities. Scientists tell stories about how the things we study work, develop, and evolve, and about how we come to be interested in them. Here I add a third domain (Secularity) to Gould's two "non-overlapping magisteria" of Science and Religion, and I review previous work on the parallels in elements between story-telling in literature and science. The stories of each domain have different criteria for judging them valid or useful. In science, especially historical sciences such as biology and geology, particular scientific methods and approaches both structure and test our narratives. Relying on the narrative assumptions of how certain processes, such as natural selection, are supposed to work is treacherous unless they are tested by appropriate historical patterns, such as phylogeny, and rooted in the process of natural mechanisms. The structure of scientific explanation seen in peer-reviewed papers and grant proposals obscures true narrative within a formulaic sequence of "question, methods, materials" and so on that is quite different from the classic narrative of folk-tales and novels, producing an "anti-narrative" that must be "un-learned" before it can be communicated to non-scientists. By adopting some of the techniques of classic story-telling, scientists can become more effective in making our ideas clear, educating the public, and even attracting funding.

Introduction

This is a story about how scientists tell stories, and don't tell stories. Or rather, if you like, it's about how scientists construct narratives and, as it turns out, "anti-narratives." Stories are common to all branches of human thought. We scientists tell two kinds of stories. One is about our research: how birds evolved; how trees and forbs became adapted to fire, and how animals adapted to those plants and their landscapes; how a free-living organism was co-opted to become a mitochondrion. The second type of story is our own: how we became interested and even obsessed with our research topics; how we discovered the source of the genes that make the turtle shell; how we discovered the long-lost fossil quarry that established that *Tyrannosaurus rex* adults and juveniles hunted together.

This is a story about what stories do in science, how we construct them, and how we judge how good they are. For comparison, we'll look at stories in other realms of human thought. Then we'll compare how we tell our stories to each other, in the form of scientific publications, with how we can effectively tell stories to non-scientists—or, in common parlance, normal people. This will introduce the concept of "anti-narrative."

Our stories about our research are of interest to both scientists and non-scientists, and we tell them in different ways to both audiences. Stories about ourselves as scientists are usually of limited interest to other scientists (except if they already know you), but are often of interest to non-scientists, especially if the two types of stories are blended.

Many scientists think that it's disingenuous to "tell stories" about their research, that this is an unnatural way to explain what they do. To the contrary, the "anti-narrative" of most scientific papers obscures understanding by all but specialists in a sub-field. Narrative is not only natural but necessary.

The stakes are high, especially with decreasing support for science and science education, and increasing disrespect and distrust for scientific methods, evidence, and authority, tentative as the last may be.

Who owns narratives?

Gould (2002) meant to smooth the waters between science and religion when he tried to establish them as two "non-overlapping magisteria," each with truths to tell and very different ways to tell them. For him, the purview of science was the natural world, whereas religion handled theology, morals, and ethics. Neat division: problem solved.

Well, maybe not so much. Missing from Gould's formulation was consideration of about 90% of what people are usually concerned with: traffic laws, tax structures, schooling their kids, electing responsible public officials, what music to listen to, what movies to watch, how to find meaningful relationships, and so on. These concerns regard neither science nor religion, unless you live in an extreme theocracy where everything recurs to someone's interpretation of religious doctrine. The fact is that we need a third magisterium, and I propose that we call it the Secular (Fig. 1). We need this magisterium—or, as I would prefer to call it, a Domain—for the quotidian things mentioned above, which cannot conceivably be within the purview of either science or religion. But more fundamentally, we construct our governments in secular terms, unless they are bound by religious laws (contrast theocracy with democracy). Even if the Divine Right of Kings is accepted, that monarchy has to devise practical laws that are neither theological nor scientific (recognizing that the scientific was the same as the theological until the Enlightenment). This is the domain of the Secular. Yes, it marginalizes both religion and science, beyond what Gould conceived. But sometimes there is more than Heaven (religion) and Earth (science) in philosophy.

Beyond this, most people don't want sectarian religious views to prescribe morality and ethics to everyone. We develop secular systems of laws and standards of behavior, and systems of government. In the Western world, we've been doing it since Plato. Science isn't involved here, because it's only interested in questions about the natural world. This is why the third Secular magisterium is critical.

Why be concerned with these magisterial domains? Because it's important to understand how stories are told, and how they differ among these domains. One might define "myths" as stories that come from cultures other than your own, but the implication is that all cultures have "myths." What functions do myths serve? They are shared narratives that define and unite a community. They preserve its theology and history. Those stories are the glue of these cultures. Secularity, the second domain, shows us that we can have governments without theology, and histories that aren't guided by supernatural beings. Those histories forge our governments and our laws. And the majority of our fictional and biographical literature is secular. So stories are important here too.

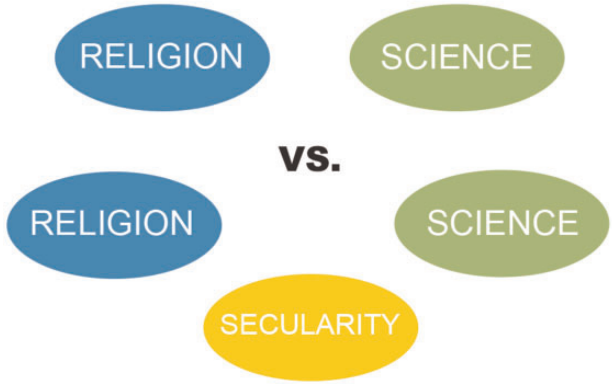

Fig. 1 Above, Gould's (2002) division of human knowledge into the two "Magisteria" of Religion and Science; below, the division advocated here into the "Domains" of Religion, Secularity, and Science.

What about science? Every field of science tells stories. Our stories follow prescribed methods. Each field has its own. We tell stories about how we developed our research projects and came to our discoveries. But not all sciences are about historical phenomena. In the earth sciences and biological sciences, we are. We have stories about the origin of Life, of Pangaea, of whales, of flight. Narrative comes far easier to us.

The bottom line is that all domains tell stories. We tell stories about how our study objects came to be, and about how we came to study them. So let's consider the structure of narrative, to see just how we tell stories.

Fables in literature and narratives in science

How do scientific stories differ from those of classic literature? Consider Vladimir Propp's (1925) scheme of the sequence of events in a fairy tale (Table 1). They're familiar to all of us (and we'll see them again when we discuss human evolutionary narratives). "Jack and the Beanstalk," "The Odyssey," and "Harry Potter and the Philosopher's Stone." Note that the "quest" only succeeds because a "gift"

Table 1. The structure of narrative in the folk-tale (the latter after Propp [1925] and Landau [1984, 1991])

Structure of narrative in the folk-tale:
Hero met → problem introduced → "quest" required → first test (fail) → "gift" → transformation → test again → triumph → problem resolved!

from some donor transforms the hero. Now consider this in a scientific context. When scientists do research, it can be thought of as a quest, and the "gift" of funding (NSF, NIH, etc.) to develop our research data "transforms" our question into a "triumph" of an answer. That follows classic narrative structure. It can be seen in the works and analyses of Bruno Bettelheim, Joseph Campbell, Jerome Bruner, Robert Graves, James Conant, and many others.

I will argue here that our professional scientific training un-teaches us how to tell stories, and pushes us into an unfamiliar format that we quickly learn we must master in order to succeed in our profession. In other words, you jump through the hoops to develop a grant proposal, in which you effectively pervert your story of discovery to satisfy a formula that asks you to define a hypothesis and methods and express preliminary results. This is far from a story about quest and discovery. When you write up your results for publication, you get the same perversion of narrative. (More on this later.) Here we want to stress the ubiquity of narrative in domains and ask what makes a good story in each domain.

Beginning with religion, most people will acknowledge that every religion has its stories, which we call myths, unless it's our own religion, and then it's a sacred text. Shared narratives define and unite a community, which is usually not only religious but historical and demographic. They preserve its theology and history, and often its morals and ethics.

Secularity shows us that we can have governments without theology (e.g., Plato's Republic), and histories that aren't guided by supernatural beings. Those histories forge our governments and our laws. And the majority of our fictional and biographical literature is secular. So stories are important in the secular realm too. They can be creative narratives, ranging from Tess of the D'Urbervilles to 1984. They can be historical narratives that cultures tell themselves, sometimes self-serving, of nations and peoples, from the Old Testament to Manifest Destiny to America First, and even to the Aryan fantasies of the Nazis.

Science is not historically preoccupies with morals and ethics, possibly because ethical and moral propositions are difficult to test empirically; but every field of science tells stories. Our stories follow prescribed methods. Each field has its own, and in two ways. First, in all fields we tell stories about how we developed our research projects and came to our discoveries. But not all sciences are about historical phenomena. In the earth sciences and biological sciences, we are. We have stories about how mammals evolved, the origin of grasslands, and why warm-bloodedness evolved twice in animals. Non-historical sciences such as chemistry and physics have few of these stories, because their phenomena usually do not depend on time and space (Origin of calcium? Origin of quarks?). But they have great stories to tell nonetheless.

What makes a good narrative, regardless of domain? First, an exciting story, with plot twists and challenges, is critical for stories in the domains of religion and secularity. In science we want to know that the researcher has a good problem, with acceptable methods and appropriate materials. Any narrative wants to have a sympathetic protagonist (Jack and his beanstalk; Noah; Harry Potter), and sympathetic scientists study ways to combat disease, to understand ecological relations of species in communities, to learn how animals evolved adaptations critical to meeting new environmental challenges. In this way we also document, in all domains, why our "quest" is important. The protagonist must also act ethically and properly. And we must not leave out the storytelling skills of the author: from Aesop to Sagan, the course of the story must be clear and well-written. And in science, the conclusions must follow the data.

Let's turn now to a particular story: the origin of what makes us human. Misia Landau, an historical anthropologist, analyzed the stories about the evolution of human features that were developed by 19th century and early 20th century paleontologists (Landau 1984, 1991). There is a sequence of features—moving left to right in this picture (Fig. 2)—of coming down from the trees, going bipedal, getting bigger brains, establishing communication—and these features were universal to all stories. But every story put them in a different order.

It became more interesting when Landau took Propp's (1925) classic folk-tale components and plotted them against the anthropological hypotheses of the sequence of acquisition of human features (Fig. 3). There's a hero, he has a challenge, he goes on a journey, and so on. But again, in every story the sequence of events was different.

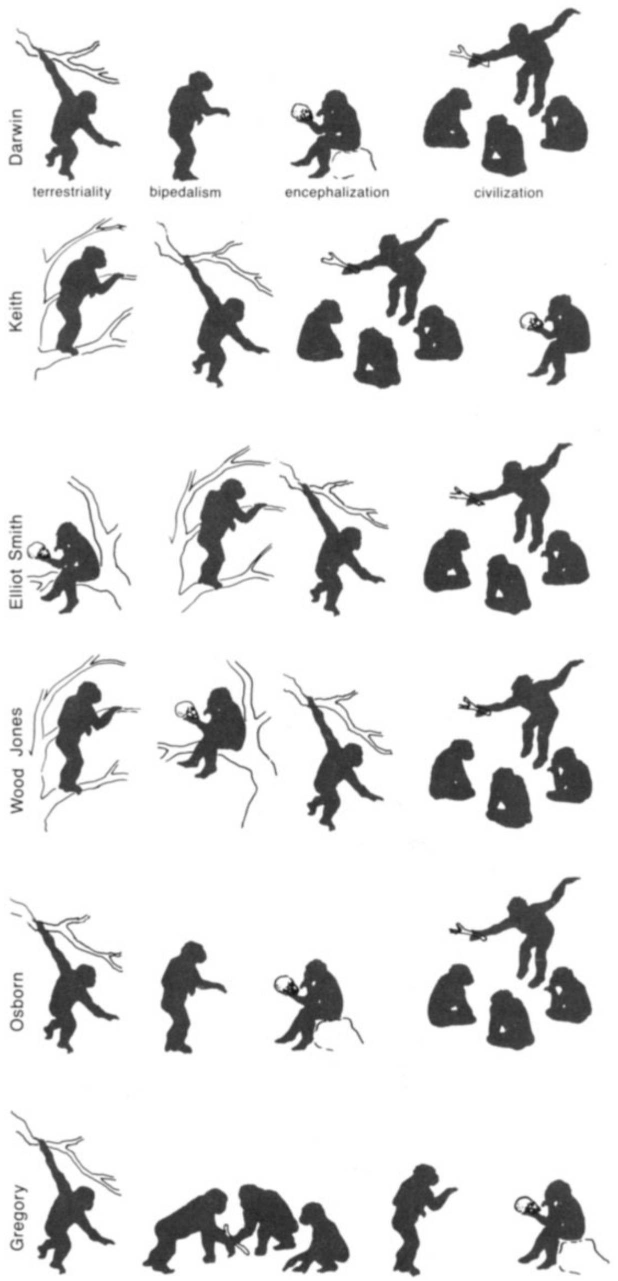

Fig. 2 Landau's (1984) comparison of the sequence of evolution of features historically deemed critical to the evolution of humans (bipedality, terrestriality, communication, encephalization), as seen by prominent late 19th- and early 20th century paleoanthropologists (Darwin, Keith, Elliot Smith, Wood Jones, Osborn, and Gregory). Note that each sequence is different.

Testing the narrative: pattern, process, and story

How can this be, if science rests on testable hypotheses supported by evidence? The answer is that iron-clad evidence is great when you have it; and when you do not, you construct testable hypotheses based on evidence from reasonably similar cases that evince patterns and processes that you expect have been working in your case. But you still have to test these hypotheses as new evidence comes to light. Darwin, Osborn, Keith, Elliot Smith, and the others lacked most of the evidence that we now have—although arguably we still don't have enough to work out this sequence unambiguously. Knowing what they knew, they tried to reconstruct how the features of humans were assembled.

So the question we ask now is whether and how we can discriminate among stories to try to decide which has greater merit. Is it enough for science merely to prefer one story over another? All those narratives about the journey of the hominid hero—don't they presume that each step in this journey is adaptive, shaped by natural selection? Gould and Lewontin (1979) famously attacked this assumption in their paper about the spandrels of the cathedral of San Marco. Are we just telling stories about evolution, they asked, if we convince ourselves that every evolutionary pathway is shaped by natural selection?

Dolf Seilacher found a way out of the adaptationist paradigm by showing that more than ecology and adaptation can shape morphology (Seilacher and Gishlick 2014; Fig. 4). Phylogenetic legacy—doing or making a feature or behavior because your lineage has always done it that way—can explain a lot. For example, all sensible water birds—gulls, pelicans, shearwaters—catch fishes in their beaks. But the osprey grabs prey with its feet. That's because it's an eagle, and that's how raptors do it. Seilacher called that phylogenetic legacy.

Another important factor determining morphology is material parameters, or the features of the skeleton itself. For example, if the inorganic component of our bones were made of silica instead of calcium phosphate, how would our movements be different?

These latter two factors are alternatives, or if you will, complements, to the "adaptationist paradigm" in testable scientific terms. They are an antidote to the notion that natural selection is pervasive and all-powerful, even when selection is not measured. And they remind us what we are responsible for testing and not simply assuming. However, it can be argued that neither Eldredge and Gould nor Seilacher provided sufficient criteria by which to assess adaptation (the result of natural selection) or alternative explanations. It is one thing to show that there is no evidence in a given case of natural selection, but that does not show that it did not act. A complete explanation would provide the phylogenetic pattern of related organisms that show the sequence of the acquisition of features, and the processes by which these features evolved.

Fig. 3 Landau's (1984) similar depiction, following the same authors as in Fig. 3, of the sequence of events in human evolution, following Propp's (1925) formulation of the folk-tale narrative. Again, each sequence is different.

A different criticism of an adaptationist paradigm, fueled by natural selection, has always come from our loyal opposition, the creationists. This one is important to take seriously, because polls have shown for decades that a plurality of Americans don't just misunderstand evolution, they reject it. It's easy for evolutionists to make up a story, for example, about how a bacterial flagellum could have evolved from small mutations in proteins that "favored" a propulsive tail. Intelligent design advocates, on the other hand, could as easily claim that the flagellum is too complex to evolve, because if any of its 40 proteins is removed, the flagellum stops working (these and other creationist crypto-problems are detailed in Wells [2002]; for a critical review see Padian and Gishlick [2002]).

Two competing stories; how do we resolve them? One way is by attacking the creationist story because it would require supernatural intervention, which

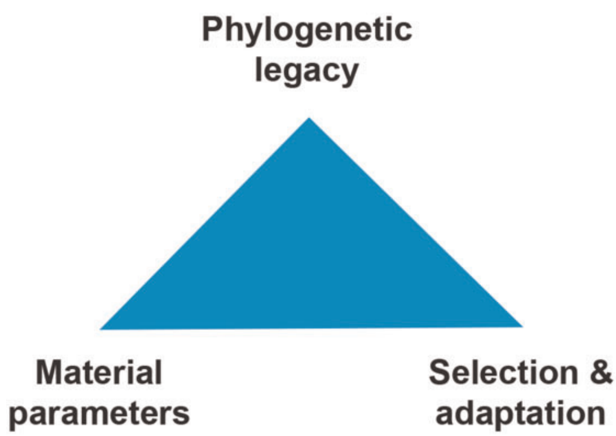

Fig. 4 Seilacher's formulation of *Konstruktionsmorphologie* (constructional morphology), in which simple adaptationist evolutionary stories are replaced by a triumvirate of factors that also include phylogenetic legacy and material properties (see Seilacher and Gishlick 2014).

may be possible but is outside the purview of science (at least since the Enlightenment). Another way is to test our hypotheses using the methodology of the natural sciences. Any hypothesis about how a feature or function involved requires a phylogenetic hypothesis (Eldredge and Cracraft 1980; Brooks and McLennan 1991). Applying phylogenetic methods, the pattern clearly shows that the locomotory function of the bacterial flagellum is a derived condition. It turns out that the flagellum works as a propeller even when it lacks a great many of its proteins, but if it lacks too many it still plays a role in the T2 immune system. Using phylogenetic analysis, we can show how outgroups to the locomotory bacteria have other functions, and that a propeller function plausibly evolved from these (the diversity of bacterial flagella is explored in Chen et al. [2011], the transformations of structures and functions are exemplified in Van Ditmarsch et al. [2013] and Wong et al. [2007], and evolutionary and phylogenetic considerations are taken up by Pallen et al. [2006] and Pallen and Matzke [2006]). However, as noted above, the pattern is not enough to establish a complete evolutionary explanation; we also need to understand the processes and mechanisms behind it (Padian 1987). In this way the story becomes not only about what happened, but about how; and hypotheses of process and pattern become mutually testable.

Note that two kinds of stories are being told here. The first is the explanation of what happened: the process of evolution. The second is the story of the pattern of phylogeny, against which we test the story of process. This is how we escape the creationist conundrum, and the sometime criticisms of other domains against scientific explanation. Unlike most ways of thought in other domains, scientists are constantly asking themselves "How would I know if I'm wrong?" Our stories are self-correcting, so they are constantly developing.

But we do not always correct our stories. Table 2 contains a set of statements about natural selection. Some we assume but seldom test; because natural selection has been identified in some situations, we presume it is operating in others, usually without testing it. Regardless of the general veracity of any of these statements, we always have a responsibility to test hypotheses. Without testing, we have attractive stories that may not be wrong, but they do not explain to an audience how science is done and how it differs from other domains.

Table 2. A series of statements about natural selection

"Just-so-stories" about natural selection?
• By definition, adaptation is shaped by natural selection.
• Natural selection is pervasive and very powerful.
• Natural selection optimizes the features of organisms.
• The most fit individuals leave the most offspring; therefore, those with the most offspring must be the most fit.
• We know how natural selection works.
• We can infer "what natural selection would be expected to do" when observing a new system and especially when explaining the evolution of a past adaptation.

Some are plausible, some are not; two are tautologies; some are uncertain; most need to be tested, not assumed. All of them affect our stories about natural selection and evolution.

Fables and narratives in human evolution

Landau (1984, 1991), following Propp (1925), neatly showed the parallels between fables—literary stories—and reconstructions of events in the historical sciences (note that "historical" contains the term "story"). The "quest" motif, when applied to origins and evolution of specific taxa and adaptations, can take on an orthogenetic cast, as if the fates of the organic beings in question were pre-ordained. (This is why Darwin avoided the term "evolution" in *The Origin of Species*: in his day the word denoted predetermined processes such as the development of an insect larva or the fiddlehead of a fern.)

But there are other kinds of fables that historical scientists tell each other. Many of these have historically been lodged in the discipline of human evolution or paleo-anthropology, and more recently in "evolutionary psychology" and "evolutionary medicine." (The last two fields appear to be founded partly on the tenets that most or all of our psychological features are adaptations and we should study them as such, and that clinical approaches to human health should recognize how the human body has adapted, or not, to its environmental conditions: both adhere to the "adaptationist program.")

More generally, in terms of basic structures and functions, ideas about human evolution have tended either to take an adaptationist approach to our features, or to select another primate as a "model" for how our human features may have evolved (Zuk 2014). An example of the former is the supposition that our hominid ancestors were adapted for long-distance running on plains and savannahs. Yes, a few living groups of hunter–gatherers pursue this strategy to hunt ungulates on vast plains. But this notion as a general proposition may be unlikely for several reasons. Our remote ancestors were arboreal; our metatarsals are short and our gait is plantigrade (fast-running animals are digitigrade or unguligrade); and human runners suffer a variety of back, hip, leg, and foot problems that non-human runners do not. Compared with arboreal ape outgroups, humans are better adapted for terrestrial progression. But we would have to know much more about the primordial climates, environments, and social organization of ancient hominins (and to assume that they were uniform in time and space, which is unlikely) before this hypothesis would be strongly testable.

An example of the latter ("primate model") approach begins with the contention that the bonobo (*Pan paniscus*), because like humans it has low intersexual difference in size (often mischaracterized as "sexual dimorphism"), might be a good "model" for what our human ancestors were like. Because the bonobo experiences a tremendous amount of social interaction through sexual intercourse (which does not result in a higher reproductive rate than in other primates) that is promiscuous with respect to sex, age, and social status, some primatologists have argued that polygamy was the original hominin condition (e.g., Ryan and Jethá [2010], but see Saxon [2012] and Zuk [2014]).

Regardless of the potential validity of this proposition, the bonobo is not an apt comparison, for reasons that relate both to phylogenetic pattern and evolutionary process. First, it is phylogenetically unusual, and even unique, among apes in its sexual behavior. Second, it is only distantly related to *Homo sapiens*: its closest relative is the chimp *Pan troglodytes* and then (if one excludes the gorillas) the general hominin lineage, beginning with "australopiths" and including *Paranthropus* and *Homo habilis*, *Homo erectus*, *Homo ramidus*, and so on—all of which have higher intersexual differences than the bonobo (so low difference in bonobos and us is merely convergent). The chimp and human lineages are generally held to have diverged 5–7 million years ago. Third, the bonobo is the smallest member of the primate group under consideration, so we would hypothesize that lower sexual difference evolved merely on the basis of the evolutionary process of allometry: *Paranthropus robustus* is the smallest known hominin with adequately characterized male and female features (assuming that males and females are adequately characterized), and its intersexual difference is lower than in all other apes except us (McHenry 1992). But the small sexual difference in us humans, being among the larger apes, is actually something to explain evolutionarily (by testing hypotheses). For all these reasons, plus the rare incidence of polygamy in living human groups, the bonobo is a poor model for ancestral humans, let alone hominins in general. This example shows how evolutionary narratives can be tested by processes and patterns of evolution.

The story so far ...

Stories are universally told in all domains (secular, religious, and scientific). They transmit culture, hold together traditions, and recount shared histories. Stories in all these domains have common features. Differences often relate to values placed on elements of a story: some elements reaffirm cultural identity or moral lessons, some provide a great plot, and some are testable and use methods accepted by the community in question. Stories in science, like others, can be based on belief; but if they aren't both testable and tested, they remain simply stories. And in evolutionary biology, stories with narrative sequences can be tested by phylogenies, and by knowledge of evolutionary, developmental, and physiological processes.

Perspectives from the social sciences on scientific communication

It will not surprise most readers that scientific communication is a strong focus of social science in both theory (e.g., Norris et al. 2005; Avraamidou and Osborne 2009) and practice (e.g., Dahlstrom 2014). The role of narrative is a cynosure for several reasons. Avraamidou and Osborne (2009) discuss the different ways in which stories can be told in science, and compare their major features and efficacies. Theirs is a good introduction to the literature on the uses of narrative in science. Other studies focus on how science communication actually works. Dahlstrom, for example, asks about the relationship between scientists and journalists when telling their stories. Is it ethical to persuade or only to communicate objectively? What responsibility do both the scientist and journalist have to their audience? Given that media outlets generally have a public and sponsors to satisfy, what are their choices in choosing and presenting stories?

A full consideration of social science perspectives on science communication is outside the scope of this paper, but interested readers may wish to consult journals such as *Science Communication* and *Public Understanding of Science* as well the recent National Academy of Sciences report on science communication at https://www.nap.edu/catalog/23674/communicating-science-effectively-a-research-agenda.

The structure of scientific communication: narrative vs. "anti-narrative"

We move now from "What makes a good story in science?" to "How does what we do differ from how we explain it?" The latter question is fundamental to how we translate our research—our "stories"—from how we communicate it. What I call "anti-narrative" is what happens when scientists translate their work into peer-reviewed articles and grant proposals. This is a simulacrum of scientific work, the classic formula of the "scientific method" that is still purveyed in schoolbooks (but for an antidote, see https://undsci.berkeley.edu/): state the problem, provide your methods and materials, lay out your experiment, list your results, discuss the conclusions of your work.

This bare-bones approach works for some experimental studies, although it still obscures the real story of the work (see below). Such a standard format for scientific publication has objectivity, we are told, and it forces authors to be brief and concise. But think of the first time you opened a scientific paper in a peer-reviewed paper. Perhaps you struggled with the jargon or the stiff syntax, as you may observe your students doing now. Did you find that the elements of the scientific story that you expected to find were present, and were they in the order you expected them? If they followed the format above, they weren't in the order you would find them in a typical story. The formats are compared in Table 3.

Take the example of the discovery of Tiktaalik, one of the most exciting events in recent paleontology (Daeschler et al. 2006a, 2006b). The articles describing it in Nature were perfectly competent; but they were disjointed with respect to the story of the work, as scientific literature forcibly is. The authors discussed first the geology of the area, then the conditions of preservation in the sediments. Then they named and described the new animal. They estimated where it belonged in the family tree of vertebrates. Then they talked about biogeography. At the very end they discussed what some of the unusual and possibly transitional features of the new animal might mean for vertebrate evolution. And that was it.

In contrast, if you watch Neil Shubin explain the find on YouTube (http://www.youtube.com/watch?v=yvDQCa7rleI), he tells you why they undertook the work to begin with; what the importance of any results would be; how they knew where to look; how many frozen field seasons they had to work in Greenland before they got lucky; how one crew member always had to stand guard with a rifle, watching for polar bears; and how exciting it was when Steve Gatesy unearthed the first bones of Tiktaalik and they realized what it was.

Should all that information be part of a formal scientific report? Perhaps not all. But a sense of discovery enhances your readers' sense of the importance of what you're reporting and why you undertook the work. This is not part of the standard "anti-narrative" of scientific publication. Even the Abstract, which is an opportunity to incorporate such aspects, is often wasted on a "table of contents" approach or a litany of the paper's topics in an oddly passive voice ("Here a new species is described . . ."; "Implications are discussed"). Ironically, submissions to journals are now often required to have a "non-technical abstract" (that is of course not published) in which the authors are presumably meant to explain what they did to someone who isn't a specialist. But this still doesn't guarantee that a real "story" about the research will be told.

Table 3. Comparison of the format of a typical scientific article with the structure of narrative in the folk-tale (the latter after Propp [1925] and Landau [1984, 1991])

Format of a typical scientific article:

- Abstract
- Introduction
- Materials and Methods
- Results
- Discussion
- Conclusions
- Acknowledgments
- Literature Cited

Structure of narrative in the folk-tale:

Hero met → problem introduced → "quest" required → first test (fail) → "gift" → transformation → test again → triumph → problem resolved!

Convincing scientists that narrative is important

Because Science Communication is not (yet) considered a primary objective of graduate education, beginning scientists have to learn osmotically how to present their research to the public. There are good reasons to do this. First, you will become a better teacher. You improve by becoming used to thinking of your audience's needs and about what they already know and don't know about what you're telling them. You also think about how they can most effectively hear what you're trying to say, and that determines how you present it. Second, it can help with grant proposals. Reviewers often have a lot of competing projects to sort out. Projects will command more interest (and we hope higher scores in the end) if they are written in prose that is not situated in impenetrable jargon, and comes quickly to the importance of the work through an accessible narrative. And third, potential donors to your work will be more interested in contributing if they understand it. This means not only using accessible language and avoiding jargon, but telling the story about how you got interested in the work, why it's important, what it can lead to, and how you've engaged others in the work (especially students: donors love to know that students are getting that "eureka" moment in their training).

There are two obstacles to overcome: the public perception of scientists, and your training as a scientist. The days of automatic respect for anyone with a degree are long over; organized campaigns against established knowledge serve a variety of contemporary political, economic, and social purposes (Nichols 2017). The kindly old doctor and the helpful humanitarian scientist of the books and films of the last mid-century have been replaced, increasingly since the advent of the atomic bomb, by caricatures of myopic, narcissistic misanthropes only out for their own glory (and income from allegedly lucrative government grants), if not outright bent on world domination and destruction. The late Senator William Proxmire famously gave "Golden Fleece Awards" to scientific projects that he felt were a waste of time and money because they had no direct relevance to economic or medical advancement. Current Senator Rand Paul is taking this a step farther by proposing that members of the public, uneducated in scientific research, should sit on panels that judge grant proposals (Mervis 2017). Scientists should take note: if you haven't made clear why what you're doing is important and worthy of funding, you may lose it. Consider the US Congressional election of 1994, when Representative Newt Gingrich led a charge of new Republicans to defund all government agencies that they found wanting in relevance or productivity. The US Geological Survey was greatly reduced in its resources, scope, and personnel, whereas NASA, although its funding was cut, survived in more its traditional form. NASA had spent decades educating every schoolchild about the excitement and value of space exploration; the USGS had spent comparatively little educating them about why we should know about watersheds, climate, natural resources, and the hazards of floods and earthquakes. So there is much at stake in showing more than your immediate colleagues—"the twelve people in the world who are interested in your study," as one commentator put it—why your work is interesting.

Consider a practical example: during the trial of *Kitzmiller v. Dover* in 2005 (see Padian and Matzke 2009), US Federal judge John Jones III had to decide whether "Intelligent Design," a scientifically unreviewed idea about the detection of supernatural influence on natural processes, could be permitted to be taught as science in public schools. There was, to say the least, a lot at stake here. We scientists on the side of the plaintiffs knew that we would have to make our scientific philosophy, methods, and evidence very plain and understandable to the judge, who was well-educated but not a specialist in science. So we fit our testimony squarely into the framework of a narrative about how science is done and what its rules are. A sample of this can be found in my own testimony (https://ncse.com/creationism/legal/padians-expert-testimony), which was greatly improved by trying to explain science to our scientifically unlearned attorneys. The expert witnesses on the other side, in contrast, tended to use complicated explanations and jargon that left the judge stymied. The result was perhaps the most one-sided victory in American jurisprudence (https://www.aclu.org/files/images/asset_upload_file577_23137.pdf).

To be effective, we had to make scientific language accessible and memorable. So, instead of describing to the judge the "avian carpometacarpal joint," I used the term "the pointy part of the Kentucky Fried Chicken wing." (Shortly thereafter, he broke court for lunch.) The memorable matters: The last words of testimony in the trial were repeated by Judge Jones in his decision: "Padian bluntly and effectively stated that in confusing students about science generally and evolution in particular, the disclaimer makes students 'stupid." That's not the kind of language that a scientist would use every day; but there are times to say things for effect. And scientific narratives have to be effective.

Moving from "anti-narrative" to narrative: practical suggestions

How then do we overcome our training to fit research into an "anti-narrative" format and to obscure prose with inaccessible jargon? We have to "un-learn" what we've been taught.

1. Spend more time explaining what you do to "normal" people in an informal setting. If you only talk to your labmates and a few other colleagues in your department, consider starting with your non-scientist roommates and friends, undergraduates whom you may be teaching a completely different subject, and others whom you know socially through community or church groups. Because they know you as a person, they will be sympathetic. Present your story to them and ask for all possible questions and feedback. The seemingly least important or relevant query may turn out to be critical in revising your narrative.

2. Begin not with "here's what I do" but "here's how I got interested in what I do, and why it's

important." As you explain your work, like the hero in Propp's folktales, you'll make clear how the problem presented itself to you, how you undertook your "quest," what the obstacles were, how you got help from others, and how you arrived at some real ground-breaking discovery. And don't omit to explain why you're the right person to do this work. Sometimes you get lucky, but fortune favors the prepared mind, and you've had valuable training that your audience will want to appreciate. That's your story.

3. Develop a series of talking points, a 30-s "elevator pitch," or an illustration you can quickly sketch on anything from a napkin to a tablet that will get across the gist of your research in accessible language in a very brief period of time. You can practice them with a variety of familiar audiences and use them when appropriate—notably with potential donors.

4. Consider doing your next poster at a scientific meeting with virtually no text—or as little as possible. No abstract, no methods, no conclusions; minimal data. Put labels on figures only to show indispensable structures. This will not work with every subject, but will work with more than you might think. Write a title that conveys the problem, not the answer: "How do monarch butterflies find milkweed?" rather than "The role of glysophate in monarch butterfly chemoreception". Use a wordless flow of arrows and symbols to connect illustrations (which now can be larger). You provide the words when people visit your poster. You make eye contact immediately; you don't have to wait politely while they look over and try to read your paragraphs and decide if they have any questions for you, or if they'll just move on.

5. Write a popular article about an aspect of your research—particularly one that lends itself to a narrative format—for a general audience. It could be for the newsletter of a naturalists' club, a local newspaper, or a house organ of your institution. The last option is particularly attractive if it reaches an audience of alumni, because they particularly enjoy hearing that good teaching and research still thrive at their institution. If you mention the stories of students who work with you and become trained and inspired, the effect more than doubles. Alumni interest quite frequently translates into contributions to research.

Conclusion

There are many good reasons for scientists to tell their stories more effectively. Scientists are increasingly dehumanized and marginalized in social discourse and popular media. Threats to scientific research, and even to the credibility of scientists concerning scientific problems, are continually mounting. As government funding for research decreases, scientists increasingly need to reach the public to turn the tide of mistrust and misunderstanding and to attract funding from new, largely private sources. Private donors are usually highly intelligent, but may not be familiar with your particular field, so you will need a narrative that reaches them. Better stories also reach students, who tend to remember lecturers and course material that are presented in an interesting way, and who often go on to influence public policy and to contribute to their university's programs.

But to be effective, scientists have to "un-learn" what we've been told is good science in presenting our research and grant proposals, and develop instead a good story about science. Recur to the consideration above of "what makes a good story?" Maybe it doesn't hurt to incorporate some elements of the folk-tale—at least when you want to tell a good story to an audience and engage reporters, administrators, donors, funders, and the general public.

Another of those elements is a sympathetic protagonist. When audiences get to know you, understand your dedication to and passion for your work, and see how your research will advance important questions, you will gain their sympathy—even if your work will not yield great benefits to medicine or technology. The takeaway is that when you tell your story you get people excited about science. And when you explain your methods, they understand how science is done and why it's important that science has methods different from those of other Domains of human knowledge.

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