Integrative and Comparative Biology
Integrative and Comparative Biology, volume 58, number 6, pp. 1213–1223
doi:10.1093/icb/icy103
Society for Integrative and Comparative Biology

SYMPOSIUM

# Making Science Meaningful for Broad Audiences through Stories

Sara J. ElShafie[1]

Department of Integrative Biology and Museum of Paleontology, University of California, Berkeley, CA 94720, USA

From the symposium "Science Through Narrative: Engaging Broad Audiences" presented at the annual meeting of the Society for Integrative and Comparative Biology, January 3–7, 2018 at San Francisco, California.

[1]E-mail: selshafie@berkeley.edu

**Synopsis** Science is a search for evidence, but science communication must be a search for meaning. General audiences will only care about science if it is presented in a meaningful context. One of the most effective ways to do this is through storytelling. Stories are integral to all cultures. Studies indicate that stories even help audiences to process and recall new information. Scientists sometimes worry that storytelling will conflate empirical evidence with fabrication. But when telling non-fiction stories, it is a process of recognizing the story elements already present in the subject material and distilling the most concise and compelling account for a target audience. In this paper, I review literature, offer examples, and draw from my experience as a scientist and a communication trainer to explore how storytelling makes science comprehensible and meaningful for general audiences.

Allow me to begin this paper with a story ...

When I began studying paleontology as an undergraduate, I felt like a black sheep in the family. My relatives all had occupations that dealt with everyday problems, like feeding and healing people. Every time a relative asked me, "So what is your research about?," I got the same feeling of dread. I would try to explain my work ("I study fossil lizards that were abundant in the US Western Interior during the Paleogene!"), and they would nod politely and change the subject. Despite my passion for the field, I was inadvertently making it impossible for others to share my enthusiasm. It bothered me that I did not know how to convey the importance of my work to my own family.

I was now a year into my PhD program. As I began preparing for my qualifying examination, I decided that I needed to address my communication problem before I started my dissertation. But where to start? At family gatherings, my relatives swapped stories. I realized that I had learned a lot about their work through those stories. I needed to learn how to tell stories about my work that would appeal to them as well. If I could do that with my relatives, I could probably do that with anyone.

It just so happened that some masters of storytelling were located close to my university campus. I contacted Pixar Animation Studios to see if anyone there would be interested in coming to chat with a group of graduate students in my department. To my complete shock, I actually got a response. We started planning a seminar. I had loved Pixar movies since I was a kid, and now we were going to learn about storytelling from my childhood heroes! The timing was also perfect because I had just been invited to give a talk at a public paleontology festival called PaleoFest (Burpee Museum of Natural History 2016). I already had a talk prepared from my Master's thesis defense, but I was hoping to pick up a few tips to help tailor it for a public audience.

In our campus seminar, an artist from Pixar gave an entertaining and perceptive overview of basic storytelling tools that they use at the studio. I realized that I was already familiar with many of these terms and concepts. But I was surprised to realize that I had never thought about them in the context of communicating science. It had not occurred to me that telling a story with a protagonist and a plot could be just as useful in science as in fiction. I was also reminded by this artist that the most important rule in storytelling is to make your audience care. Even in stories about toys or monsters or superheroes, the story has to be emotionally

Advance Access publication July 30, 2018

compelling (Pixar Animation Studios 2017). Otherwise, it won't mean anything to the audience. Pixar's filmmakers had a lot more in common with scientists than I thought. Whether empirical evidence or whimsical fantasy, the goal is to connect with the audience.

When I got home that night, I was exhilarated. Storytelling was clearly the best starting point to figure out how to connect with my family, and with the public! But as I began modifying my thesis slides for PaleoFest, I started to panic. I realized that I would have to change the entire talk. My slides focused too much on the specifics of my research and offered little meaning for a broad audience ("Body size and species richness change in Glyptosaurinae through climatic transitions of the North American Cenozoic" –that'll really get the kids inspired!). What might a bunch of families and fossil enthusiasts actually care about (beyond just "fossils are cool")? How could I tie that to my particular research? I sat down and began to brainstorm.

## Introduction: making science meaningful

The dilemma in the story above may sound familiar. Perhaps you too have struggled to explain your work to your family. I'm willing to bet that you have come across scientific reports or presentations that offered no clear relevance for a general audience. Scientists are trained to be objective when conducting research. A scientist's personal perspective on his or her work blurs that objectivity, and thus technical scientific writing tends to be indifferent to the actual experience of doing science (Olson 2009, 2015; Baron 2010; Schimel 2012; Olson et al. 2013; Green et al. 2018; Padian 2018). Communication, in contrast, is about building understanding between different perspectives. To do this, we cannot assume that objectivity will be appealing (Fiske and Dupree 2014) or that scientific evidence will speak for itself (Dean 2009; Baron 2010; Schimel 2012; Fischhoff et al. 2013, 2014; Luna 2013; National Academy of Sciences 2014, 2017a, 2018). Broad audiences understand science when we make it meaningful to them (Dean 2009; Olson 2009, 2015; Baron 2010; Olson et al. 2013; Alda 2017; Rather 2017).

One of the best ways to make an idea meaningful is through storytelling (Avraamidou and Osborne 2009; Olson 2009, 2015; Olson et al. 2013; Hadzigeorgiou 2016; Alda 2017; Rather 2017; Mazurkewich 2018; Padian 2018). Stories have always been integral to human culture (Campbell 1949; Vogler 2007; Gottschall 2012; Harari 2015; Padian 2018), and are deeply rooted in our cognitive processing (Bruner 1986; Falk and Dierking 2000; Kahneman 2011; Cron 2012; Sanford and Emmott 2012). Stories put new information into a familiar context, which both focuses attention (Schank and Abelson 1995; Hasson et al. 2008; Stephens et al. 2010) and elicits emotion (Barraza et al. 2015; Zak 2015). Stories help an audience to comprehend, recall, and care about the content presented (Bower and Clark 1969; Graesser et al. 2002). Storytelling can therefore help scientists to engage with broad audiences and make even the most abstruse scientific concepts accessible (Olson et al. 2013; Olson 2015).

## Story, narrative, and storytelling

The difference between "story" and "narrative" depends on whom you ask (Avraamidou and Osborne 2009). Dictionary definitions often give reciprocal explanations of the terms—e.g., narrative: "something that is narrated; story, account" (Merriam Webster 2015), versus story: "an oral or written narrative account of events" (Oxford English Dictionary 2017). Sanford and Emmott (2012) offer a helpful review of literature on what constitutes a "narrative" versus a "story." They find that, at minimum, there is some consensus that a "narrative" is a series of chronological, causal events. A "story," according to their review, must include a setting (a main character, location, and time), a plot (in which the main character pursues a goal), and a resolution (outcome of that pursuit). A "narrative" tells a "story" when something unusual happens that sets the events of a plot in motion (Hühn et al. 2009; Sanford and Emmott 2012; Olson 2015). For extensive discussion of these terms, see especially Bruner (1986), Simmons (2001), Norris et al. (2005), Avraamidou and Osborne (2009), McKee (2010), Gottschall (2012), Olson et al. (2013), Olson (2015), and the references cited under the "Story structure" section.

For the purposes of this discussion, I will consider a "narrative" to be a sequence of causative events. A narrative becomes part of a "story" when one of those events is an inciting incident that sets a plot in motion. A "story," which I treat here as the more encompassing term, follows a protagonist on a journey to overcome an obstacle with something of consequence at stake. This journey will have a meaningful broad theme for the protagonist and/or the audience. I will discuss these terms in detail later in this paper.

> *A good story cannot be devised. It has to be distilled.*
> —Raymond Chandler, quoted by Schimel (2012)

This is true of fiction and especially of nonfiction storytelling. Some worry that science storytelling will misconstrue empirical evidence (e.g., Katz 2013), but the purpose of nonfiction storytelling is to offer a clear and compelling account of true events (Simmons 2001; Vogler 2007; Baron 2010; Sachs 2012; Schimel 2012; Luna 2013; Olson et al. 2013; Olson 2015), not to alter facts. Science communication, like storytelling, is a process of distilling the most salient information from a complex body of work (Dean 2009; Baron 2010; Schimel 2012; Luna 2013; COMPASS 2017). A science storyteller does not change the truth in the evidence; rather, she or he distills the story that the evidence tells. The appropriate information to include depends on the audience, the context of the communication, and the goals for that interaction (Avraamidou and Osborne 2009; Dean 2009; Nisbet and Scheufele 2009; Olson 2009, 2015; Baron 2010; Schimel 2012; Fischhoff et al. 2013, 2014; Olson et al. 2013; National Academy of Sciences 2018). Every scientist does this when writing a manuscript or preparing a presentation. A scientist who understands the mechanics of story will be more effective at it (Avraamidou and Osborne 2009; Olson 2015; Green et al. 2018; Padian 2018).

Beyond distilling information, a compelling story has enough emotional significance to be meaningful to the audience (Simmons 2001; Vogler 2007; McKee 2010; Sachs 2012). Emotional significance is also critical for effective science communication—in this context, it is often called the "So What?" factor (COMPASS 2017), "What's the Big Idea?," or something similar. Storytelling can therefore help scientists to consider the potential emotional impact of their work in addition to the scientific impact (Avraamidou and Osborne 2009; Olson 2009, 2015; Olson et al. 2013; Alda 2017; Green et al. 2018; Padian 2018).

## How do we know that storytelling improves communication?

Bruner (1985) claimed that "there are two irreducible modes of cognitive functioning" (p. 97). "Paradigmatic mode" is for rational thinking—logic and problem solving, regardless of context. The other, "narrative mode," seeks meaningful explications that are sensitive to context. Years later, after extensive research, Kahneman (2011) used a similar dichotomy to describe human cognition. He characterized "System 1" as our default mode of mental processing, constantly creating stories out of new information. "System 2," akin to Bruner's "paradigmatic mode," deals with complex problem solving and can only work in short bursts. Scientists would thus do well to speak to an audience's System 1 by telling a story, rather than exhausting System 2 with technicalities.

Recent studies indicate that people are neurologically prone to focus on content with story structure. In one experiment, Hasson et al. (2008) monitored the brain activity of four groups of volunteers while showing each group a different type of footage. The footage ranged in story intensity from an Alfred Hitchcock film (strong story, strong suspense) to footage taken in a nearby park (no story, no suspense). The people watching the Hitchcock film had the highest similarity in brain activity relative to each other; the people watching park footage had no similarity at all. This result may not seem surprising, but the implications are profound. By using story structure, especially with high suspense, a storyteller can essentially sync the brainwaves of audience members. Without a story, an audience may as well be watching pigeons.

This phenomenon of brain waves syncing while processing stories is called *neural coupling*. In a follow up study (Stephens et al. 2010), a speaker told a listener a story while scientists monitored the neural activity of both subjects. The brain activity of the listener mirrored that of the speaker. When that listener then recounted the same story to another listener, their respective brain activity still reflected that of the original storyteller. This study indicates that stories can align mental processing and memory in audiences. According to these conclusions, when you read my story in the prologue of this article, your brain activity would have resembled mine when I wrote the story. Likewise, if you retold that story to someone else, their brain activity would reflect yours.

Other research shows that stories not only facilitate information processing and recollection; they also elicit a hormonal response. In one study, Barraza et al. (2015) showed participants a short video about a father whose son is dying from cancer. In the video, the father describes his struggle to set aside his grief and make the most of his remaining time with his son. Barraza et al. (2015) found that people who watched this video had elevated blood levels of cortisol, which focuses attention, and oxytocin, which is associated with feelings of empathy (see Zak et al. 2004, 2007). These participants also had activated areas of the brain that are rich in oxytocin receptors. Barraza et al. (2015) found that they could even predict with 80% accuracy which participants would donate money to a children's cancer charity based on the levels of oxytocin in their blood after viewing the short film (Barraza et al. 2015; Zak 2015). By comparison, a control group that watched a different video of the same father and son at a zoo, without the dramatic storyline, showed no hormonal or neurological response.

Stories clearly have a neurological and even physiological effect on us. This may explain why storytelling is ubiquitous in all cultures (Campbell 1949; Gottschall 2012) and used in most media platforms (Dean 2009; Baron 2010; Sachs 2012). Given this, and the fact that most people get their scientific information from mass media once they are out of school (National Science Board 2012), the question is not whether we should be conveying science through stories, but how best to do it (Dahlstrom 2014; Martinez-Conde and Macknik 2017).

## Story structure

Story structure is remarkably consistent across stories from many cultures through history (Campbell 1949). Stories often begin with an exposition to set the scene, present a conflict that launches the rising action, and resolve the conflict in the climax and falling action (Figs. 1 and 2). German novelist and playwright Gustav Freytag first described this "dramatic arc" in 1863 based on an analysis of Aristotle's *Poetics* (ca. 335 BCE; see the 1961 English translation) and Shakespearean dramas (Freytag 1900). Propp (1925) found that many folktales have a common sequence in which a main character sets out on a quest and undergoes a series of tests (see Padian [2018] in this volume for further discussion). Campbell (1949) studied myths and stories from all over the world going back centuries and also found that many stories follow a common arc with similar elements. In this model, commonly known as "The Hero's Journey," a protagonist sets out to solve a problem, undergoes a series of trials, and emerges with new knowledge about the world and herself (Fig. 2). This structure is the basis of almost every story ever produced for mass audiences, from Dante's *Inferno* (1320; see the 2002 English translation [Alighieri 2002]) to *Star Wars* (Lucas 1977; Vogler 2007). Therefore, following this structure, even loosely, can put science into a familiar context for many audiences (Olson 2015).

Scientific manuscripts and presentations commonly follow a structure that actually reflects a dramatic arc, in a sense. A typical manuscript starts with an Introduction (Exposition), followed by Methods (Rising Action), Results (Climax), Analysis (Falling Action), and ends with Discussion and Conclusions (Denouement or Resolution; Fig. 1; see Schimel 2012; Luna 2013; Olson 2015). Note that this "IMRAD" format does not follow the actual sequence in which the events of the study took place (see Padian [2018] in this volume for further discussion). The resemblance of the IMRAD format to a dramatic arc may suffice as a narrative for many scientific audiences.

Although most audiences will recognize the structure of a dramatic arc, it is often necessary to start with the "So What?" aspect of the story to hook an audience's attention (Schimel 2012; Luna 2013;

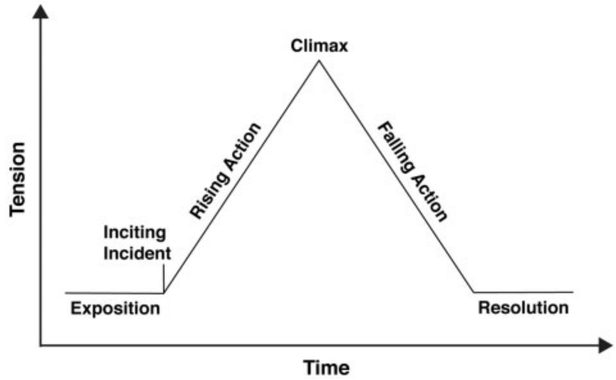


**Fig. 1** Freytag's "pyramid," also known as the "dramatic arc," showing a five-part story structure with rising and falling tension over time. Based on Freytag (1900).

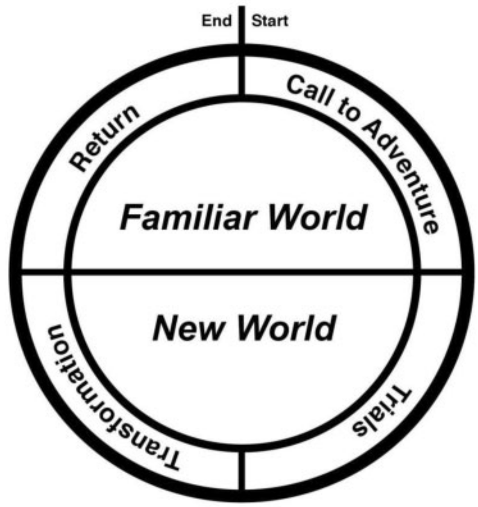


**Fig. 2** "The Hero's Journey" story model. The protagonist, or hero, starts in a familiar context (for both him/her and the audience) and receives a "Call to Adventure" that initiates a journey into a new context. The protagonist undergoes a transformation and returns to the familiar context with a new perspective. Based on Campbell (1949). See also Vogler (2007) and Olson (2015) for extensive discussion of The Hero's Journey in the contexts of film and science communication, respectively.

COMPASS 2017). Journalists typically start a story with the main point (the "lede"), then provide the most important details, and offer more background information toward the end of the piece (Dean 2009; Baron 2010). This approach also works well in situations that require you to hook the audience immediately, such as research proposals or short-span contexts (e.g., elevator pitches, conversations, and interactions with guests at exhibits and festivals; Baron 2010; Schimel 2012). You can also start with a short, concise narrative that gets right to the point and captures interest before elaborating with a longer story (see Olson et al. [2013] and Olson [2015] for extensive discussion of the "And–But–Therefore" format).

## Essential elements of story

The ingredients considered most essential to storytelling vary slightly depending on the author (e.g., see Forbes 1999; Vogler 2007; Avraamidou and Osborne 2009; McKee 2010; Schimel 2012; Olson et al. 2013 for various treatments). For the purpose of engaging broad audiences with science, I have found these five elements useful: protagonist, inciting incident, obstacle, stakes, and broad theme. If one of these items is poorly developed, the story often falls flat or falls apart.

### Protagonist

Most stories follow a single main character, or protagonist. Clarifying the protagonist in a story, and the objectives that motivate the protagonist, can help the audience relate to him and follow the dynamics of the story (Olson 2015). It will not always be essential to name the protagonist explicitly: if the story remains centered on that character, the protagonist should be apparent to the audience.

Ideally, the protagonist must be both appealing and flawed (Vogler 2007; McKee 2010; Olson et al. 2013; Olson 2015). The protagonist needs to be likeable enough for the audience to want to hear the story. Storytellers often make their protagonists adept, resourceful, intelligent, funny, or coming from humble origins. These likeable qualities are balanced with empathetic flaws, such as stubbornness, overthinking, overreacting, fear of attachment, indifference, or hubris (see Dorie Barton's commentary in Olson et al. 2013). A protagonist's flaw may even jeopardize his objective without him realizing it (McKee 2010). Forgivable flaws allow the audience to empathize with the protagonist and make the story their own.

A balance of admirable traits and forgivable flaws evokes empathy with the protagonist. An audience will be more invested in the fate of that protagonist as a result (McKee 2010; Olson et al. 2013; Olson 2015). If the protagonist is a scientist, for example, was she overconfident in her assumptions, or unaware of her own biases? Did this lead to a mistake or a setback in the investigation? It is possible to humanize scientists while emphasizing that science is an iterative process of reducing uncertainty (see https://undsci.berkeley.edu/ for more details).

It can also be useful to discuss flaws in nonhuman characters. For instance, an organism, molecule, or system may have a limitation for which it must somehow (unconsciously) compensate in order to be successful. Maybe it has a negative effect on its community, environment, or planet if left unchecked. In a story about nonhuman characters, the humans are participating in the story through the narration and the audience's reaction. The protagonist might be a migrating shark, for example, but it is the narrator and the audience who will react emotionally to the shark's story and learn something from it. The goal is not to ascribe intent to a nonhuman character in an inappropriate sense, but rather, to allow an audience member to find meaningful parallels between his own experience and that of the nonhuman character. For example, rather than saying, "the shark wanted to explore the ocean," the narrator could say, "the shark needed to find food to survive." The former might work for a children's storybook, but in order to focus on empirical evidence, it is often best to avoid anthropomorphizing a nonhuman subject and instead use comparisons or analogies to make the subject accessible.

### Obstacle

Every character needs an obstacle that stands in the way of her objective. Without an obstacle, the character does not change, and there is no story (Vogler 2007; McKee 2010; Olson 2015). Fortunately for science storytellers, obstacles are part of science. Every scientific investigation confronts an obstacle, whether it is an unsolved problem or a logistical complication.

Obstacles can arise from other characters, from external forces, or from the self (Campbell 1949; Vogler 2007; McKee 2010; Olson et al. 2013; Olson 2015). In most but not all stories, the protagonist must deal with an internal obstacle before she can overcome an external obstacle (Vogler 2007; McKee 2010).

## Stakes

An obstacle only moves a story forward if it puts something at risk. What are the consequences if the protagonist fails to overcome that obstacle? The more the protagonist has to lose, the more compelling the story (McKee 2010). The stakes should increase as the story unfolds (Vogler 2007; Olson 2015). Stakes add weight to the protagonist's actions and decisions, and get the audience invested in the story's outcome.

This doesn't mean that imminent disaster has to permeate every story. Stakes can be compelling even without a fatal threat. One failed experiment may not be a major setback in a scientist's career, but what if he is working against a deadline? Against his own search for purpose? Several obstacles can even be in play at once.

## Inciting incident

This is the event that catalyzes the story. Also known as the "Challenge," "Call to Action," or "Call to Adventure" (Campbell 1949; Vogler 2007; Schimel 2012; Olson 2015), something must happen that changes the protagonist's situation and presents a new opportunity or threat to her objective (McKee 2010). From this point on, the protagonist is in unfamiliar territory—figuratively and/or literally—and the rest of the story is the protagonist's journey to return to her realm of familiarity (Fig. 2; see Campbell 1949; Vogler 2007; McKee 2010; Olson 2015).

Whether it is a story of a scientist on a quest for discovery, an organism on a "quest" for survival, or a natural system on a "quest" for equilibrium, an inciting incident signals to the audience that the story has begun. This both focuses their attention and promises a payoff at the end of the story (Olson 2015). The rest of the story then unfolds through a series of actions taken by the protagonist, and the outcomes of those actions (Campbell 1949; Vogler 2007; McKee 2010).

## Broad theme

The broad theme of the story is something universal that goes beyond the specifics of the story. It is something that every audience member can understand. The broad theme might lie in the lessons the protagonist learns from his journey in the story. If the protagonist is nonhuman, the broad theme can emerge from the subtext of the story. The migrating shark itself may not have overcome an internal conflict, but what has the audience learned from following its journey? That we shouldn't judge based on appearances? That we are all connected? Every audience member will extract his or her own meaning from the story, based on his or her own reactions and prior experiences. But if the storytelling is effective, the entire audience will arrive at a similar point.

As an applied example of these story elements, I now return to the story that I began in my prologue. Initially, I had thought that the "So What?" of my PaleoFest talk would be something like "science is a process of discovery." But as I developed the story, I realized that the take-home message had to be deeper than that. Everyone in the audience at PaleoFest would already appreciate that science is about discovery. I needed a message that would be particularly relevant to the event, but also universal.

When I asked myself, "What compels me to study fossils?," I realized that the time travel simulation of studying the fossil record had trained me to approach problems in the context of time and space. I decided to frame my PaleoFest talk as a story about how the perspective of time and space aided my personal quest to preserve nature:

> When I was a kid, I loved nature and animals. I wanted to save the planet from climate change. When I went to college, my interest in animals led to a summer job working in a fossil lab. I learned how to clean and prepare dinosaur bones, and I started studying the science of bringing them to life. It blew my mind! As I learned how to reconstruct past worlds using fossils, I realized that I was learning to address problems by thinking about changes over time and space. This also applied to climate change.
>
> I learned that climate change predictions today depend on accurate records of climate change in the past. We have a continuous record of past temperatures (paleotemperatures) in the ocean, but not on land. This is because fossil records on land are patchy and often have large gaps. Consequently, our record of paleotemperatures on land is incomplete. We need more sources of data to construct a more complete record of terrestrial paleotemperatures.
>
> I found that other studies had reconstructed past temperatures for a specific location and time based on the body size of a single squamate (snake or lizard; Head et al. 2009, 2013, respectively). What if we could do that for longer geologic time periods using fossil squamates? I searched for a suitable study group and came across Glyptosaurinae (Squamata: Anguidae), a group of lizards that was abundant in the Western Interior of North America through the Paleogene (66–23 million years ago). I

decided to investigate whether I could use the fossil record of these lizards to reconstruct temperatures through the Paleogene. I would use maximum glyptosaurine body length in a mass-specific metabolic equation to estimate the minimum mean annual paleotemperature necessary to sustain that body size (ElShafie 2014; ElShafie and Head, in review).

There was only one problem: the known glyptosaurine record did not include any complete fossils. How was I going to measure body length without whole skeletons? Fortunately, I found that the anatomical proportions of fossil glyptosaurines are consistent with their living relatives. I was therefore able to build a regression model from measurements of living lizards and estimate glyptosaurine body length based on head length. I generated a paleotemperature curve for the Western Interior of North America through the Paleogene based on glyptosaurine body length. To my surprise, I found that the lizard-based temperatures were very consistent with other fossil proxies! These results suggest that fossil squamates can indeed be a useful proxy for reconstructing past temperatures over time and space.

I was inspired by the results of this study to keep investigating past climate change events through the vertebrate fossil record. For my PhD, I am continuing to study the reptile fossil record of North America through the Paleogene, now with a focus on how climate change affects reptile communities over time and space. Paleontology trains you to think about how things are connected to a larger system, and how that system changes over time—a very useful skill. Whether you want to be a paleontologist, a farmer, a doctor, or just an informed citizen, studying paleontology can help prepare you for life!

The talk was a hit at PaleoFest. Kids, students, parents, and colleagues thanked me for an engaging story. Most important to me, however, was the reaction of my relatives, some of whom had come to hear my talk. They clearly understood, for the first time in my eight years of fossil research, why I chose this field. And, to be honest, so did I.

This story demonstrates two types of science stories: (1) stories about scientists as people, as in the personal account that bookends the story; and (2) stories about how science is conducted, as in the account from the PaleoFest talk nested within the personal story. Both of these stories have a dramatic arc, but the focus differs. See Fig. 3 for an example of a dramatic arc for a science story, as in the PaleoFest talk (see also Green et al. [2018] for variations on a

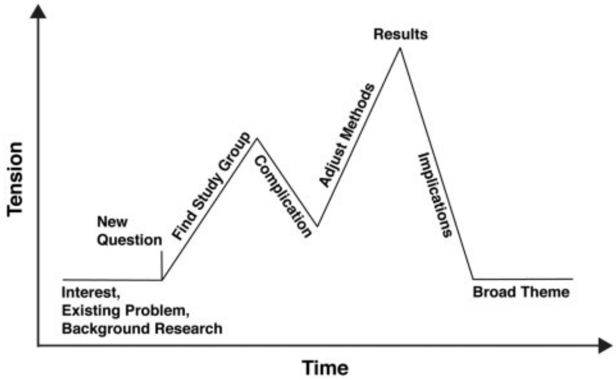


**Fig. 3** An example of a dramatic arc for a story about a scientific study. The story in the "PaleoFest" talk follows this progression. Note that in this figure, the "pyramid" of rising action and falling action seen in Fig. 1 has been broken into multiple peaks of increasing tension. A protagonist might take multiple actions and face multiple obstacles in the course of a story. Based on Freytag (1900).

dramatic arc that can apply to science stories). Note that while the broad theme of the PaleoFest talk was "Thinking about questions in time and space can help you solve problems," the broad theme of the personal story would be something like "Connecting with others connects you with yourself."

## Addressing common concerns

### Will other scientists not take me seriously if I use storytelling to engage broad audiences?

I have heard this concern many times due to a phenomenon known as "The Sagan Effect." This refers to the widely held belief that renowned science storyteller Carl Sagan was denied membership in the National Academy of Sciences because of his focus on popularizing science (Martinez-Conde 2016; but see Loverd et al. [2018] in this volume for evidence of changing views on this matter at NAS). Unfortunately, that sort of attitude still exists in academia. Too often, I hear colleagues complain that they were undermined for explaining science in an accessible way to a museum-goer, or criticized for spending any time at all on public outreach.

Many people would argue today that science communication is a critical skill for any scientist (e.g., Lubchenco 1998; Dean 2009; Baron 2010; Schimel 2012; Luna 2013; Olson et al. 2013; Olson 2015; Illingworth 2017; Mazurkewich 2018) and that efforts to engage the public with science are well worth the time (e.g., Olson 2009; Kuehne et al. 2014; Alda 2017; Rather 2017; Green et al. 2018). The National Science Foundation requires a substantial statement of "Broader Impacts" on every major grant proposal (National Science Foundation 2002). The National Academy of Sciences itself now holds a regular colloquium on "The Science of Science Communication" and has published several volumes of research on the subject (Fischhoff et al. 2013, 2014; National Academy of Sciences 2014, 2017a, 2017b, 2018). Some studies have even found that scientists who engage in public outreach are equally if not more academically productive than average (Jensen et al. 2008; Russo 2010).

### If I force empirical evidence into a story formula, won't the story be biased?

If the outcome of a story is decided first, and evidence is then selected to support that outcome, then yes, that is a biased account (Schimel 2012). But in science communication, the goal is to identify story elements that are already present in a study, and to use those elements to distill an accurate and compelling story of a study without introducing bias or fabrication. Story models such as "The Hero's Journey" (Fig. 2) offer a form, not a formula (Vogler 2007; McKee 2010). Such models are useful for understanding aspects of stories that are universally recognizable to general audiences.

A scientific study is never communicated exactly the way it happened. The IMRAD template often used to write manuscripts takes things out of context (Padian 2018). Scientists never have enough time or space to include all the details when presenting their work. They must select the most salient information, which will depend on the audience, the platform, and the main points they want to emphasize (Avraamidou and Osborne 2009; Dean 2009; Nisbet and Scheufele 2009; Olson 2009, 2015; Baron 2010; Schimel 2012; Fischhoff et al. 2013, 2014; Olson et al. 2013; National Academy of Sciences 2018).

### How can I deal with existing stories about science that conflict with the one I want to share?

Any audience will likely have some preconceptions about a topic from existing stories, especially if the topic is politically charged or ethically sensitive. For example, someone planning to tell a story that reveals the potential benefits of CRISPR Cas-9 gene editing technology (see Doudna and Charpentier 2014; Sternberg et al. 2014; Doudna and Sternberg 2017) should familiarize themselves with the plots of films depicting genetically enhanced humans (e.g., *Blade Runner*, Scott 1982) and animals (e.g., *Rampage*, Peyton 2018), as well as the anti-GMO narrative that the organic food industry uses in its marketing (Clancy and Clancy 2016). Such narratives can be an opportunity to launch constructive and balanced discussions. In order to engage people with science, it is important to be candid about what science is, in its virtues and its limitations.

### What if the experiment didn't work, or the results are inconclusive? How is that a story?

It is okay if the protagonist does not overcome the obstacle by the end of the story. This may seem unsatisfying to the storyteller, but it can make the story more gripping for the audience. They will empathize even more with a protagonist who does not get exactly what she wants. In such a case, the revelation might be that the real goal of the protagonist was something she did not see before (McKee 2010). For example, Jennifer Hofmeister studied movement and abundance patterns in the California Two Spot Octopus for her dissertation research (Hofmeister 2015). After years of dedicated fieldwork and analyses, Hofmeister's results were inconclusive. She found that it was not possible to explain patterns of abundance in this species through her study. However, her results revealed that the question was more complex than previously assessed: the octopus was highly mobile, which contradicted earlier studies. Hofmeister was inspired to continue her research on octopuses, and her hard work led to a job as an environmental scientist.

Stories are not just about solving problems: they are about discovery. In scientific pursuits, even null or negative results reveal something. A story does not necessarily have to end with a solution. It might end with a piece of the solution and more questions than answers. That's how science works. Insights can be gained from the journey. Whether the problem is solved or not, those revelations are what allow the audience to find meaning in the story.

## Moving forward

Storytelling is an iterative process. When developing a science story, it can be helpful to share a draft with people who represent the target audience and ask them what they got out of the story. Were the protagonist, obstacle, and stakes clear to them? What was the broad theme? The test audience might pick up on an emerging theme not yet considered.

Developing storytelling skills is a lifelong pursuit (Vogler 2007; Olson 2015). The good news is that it does not take long to learn the basics of story development. Using those basics in science communication makes a huge difference. Reading the papers in this volume is an excellent start. The references in this paper, as well as those listed in the other articles in this volume, offer further reading. For a helpful and entertaining overview of storytelling basics, "Pixar in a Box, Season 3: The Art of Storytelling" (Pixar Animation Studios (2017) is an open-access resource developed by Pixar with Khan Academy. Storytelling is not just a skillset; it's a mindset that one can use and develop throughout a career.

## Acknowledgments

I especially wish to thank K. Padian for his mentorship and guidance in this research. For helpful discussions, I thank L. White, J. Bean, C. Marshall, P. Holroyd, S. Sumida, R. Olson, J. Lovell, D. McCoy, A. Madison, J.-P. Vine, G. Dykstra, T. DeRose, E. Klaidman, K.C. Roeyer, M. Nolte, S. Pilcher, S. Christen, D. Campbell, R. Sullivan, P. Lin, A. Rutland, M. Coleman, C. Good, W. Trezevant, R. Dutra, K. Johnson, H. Sues, S. Sampson, C. Liu, F. Mundi, H. Kerby, R. Stockley, R. Holmes, E. Neeley, S. Ul-Hasan, and J. Hofmeister. Thank you to the UC Museum of Paleontology (UCMP) community for constructive feedback on this work. Special thanks to J. Schimel, J. Weddle, and three anonymous reviewers for their thoughtful and thorough comments on this manuscript. I thank the Society for Integrative and Comparative Biology for the opportunity to organize this symposium and publish this manuscript; my co-organizers, S. Sumida and B. Lutton; and all of my fellow symposium presenters for being part of this initiative.

## Funding

I thank the Sakana Foundation, the Uplands Foundation, and the UCMP for supporting this work. I also thank Science Sandbox, an initiative of the Simons Foundation; the Society for Integrative and Comparative Biology (SICB); the Walt Disney Family Museum; Science World at TELUS World of Science; Coalition for the Public Understanding of Science; Spacetime Labs; and an anonymous donor for sponsoring the "Science Through Narrative" symposium at the 2018 SICB Meeting, which provided the opportunity to present this work and publish this paper.

## References

Alda A. 2017. If I understood you, would i have this look on my face?: My adventures in the art and science of relating and communicating. 1st ed. New York (NY): Random House.

Alighieri D. 2002. The Inferno. New York (NY): Anchor Books.

Aristotle. 1961. Aristotle's poetics. New York (NY): Hill and Wang.

Avraamidou L, Osborne J. 2009. The role of narratives in communicating science. Int J Sci Educ 31:1683–707.

Baron N. 2010. Escape from the ivory tower: a guide to making your science matter. Washington: Island Press.

Barraza JA, Alexander V, Beavin LE, Terris ET, Zak PJ. 2015. The heart of the story: peripheral physiology during narrative exposure predicts charitable giving. Biol Psychol 105:138–43.

Bower GH, Clark MC. 1969. Narrative stories as mediators for serial learning. Psychon Sci 14:181–2.

Bruner JS. 1985. Narrative and paradigmatic modes of thought. In: Eisner E, editor. 84th yearbook of NSSE, learning and teaching the ways of knowing. Chicago (IL): University of Chicago Press. p. 97–115.

Bruner JS. 1986. Actual minds, possible worlds. Cambridge (MA): Harvard University Press.

Burpee Museum of Natural History. 2016. PaleoFest: Women in Paleontology. Rockford, Illinois.

Campbell J. 1949. The hero with a thousand faces. 1st ed. New York (NY): Pantheon.

Clancy KA, Clancy B. 2016. Growing monstrous organisms: the construction of anti-GMO visual rhetoric through digital media. Crit Stud Media Commun 33:279–92.

COMPASS. 2017. The message box workbook. COMPASS Sci Commun Inc. Available at: https://www.compassscicomm.org/.

Cron L. 2012. Wired for story: the writer's guide to using brain science to hook readers from the very first sentence. New York (NY): Ten Speed Press.

Dahlstrom MF. 2014. Using narratives and storytelling to communicate science with nonexpert audiences. Proc Natl Acad Sci U S A 111:13614–20.

Dean C. 2009. Am I making myself clear?: A scientist's guide to talking to the public. Cambridge (MA): Harvard University Press.

Doudna JA, Charpentier E. 2014. The new frontier of genome engineering with CRISPR Cas-9. Science 346:1258096.

Doudna JA, Sternberg SH. 2017. A Crack in Creation: Gene Editing and the Unthinkable Power to Control Evolution. New York: Houghton Mifflin Harcourt Publishing Company.

ElShafie SJ. 2014. Body size and species richness changes in Glyptosaurinae (Squamata: Anguidae) through climatic transitions of the North American Cenozoic [master's thesis]. Department of Earth and Atmospheric Sciences: University of Nebraska, Lincoln.

Falk JH, Dierking LD. 2000. Learning from museums: visitor experiences and the making of meaning. Walnut Creek (CA): AltaMira Press.

Fischhoff B, Scheufele DA, Fiske ST, Dupree S, Jamieson KH, Hardy BW, Pidgeon N, Demski C, Butler C, Parkhill K, et al. 2014. The science of science communication II: colloquium papers. Proc Natl Acad Sci U S A 111:13583–671.

Fischhoff B, Scheufele DA, Lupia A, von Winterfeldt D, Bruine de Bruin W, Bostrom A, Schwartz LM, Woloshin S, Klahr D, Dietz T, et al. 2013. The science of science communication: colloquium papers. Proc Natl Acad Sci U S A 110:14031–110.

Fiske ST, Dupree C. 2014. Gaining trust as well as respect in communicating to motivated audiences about science topics. Proc Natl Acad Sci U S A 111:13593–7.

Forbes C. 1999. Getting the story, telling the story: the science of narrative, the narrative of science. In: Perkins JM, Blyler N, editors. Narrative and professional communication. Stamford (CT): Apex Publishing Corporation. p. 79–92.

Freytag G. 1900. Freytag's technique of the drama: an exposition of dramatic composition and art. 3rd ed. Chicago (IL): Scott, Foresman and Company.

Gottschall J. 2012. The storytelling animal: how stories make us human. New York (NY): Haughton MIfflin Harcourt Publishing Company.

Graesser AC, Olde B, Klettke B. 2002. How does the mind construct and represent stories? In: Green M, Strange J, Brock T, editors. Narrative Impact. Mahwah (NJ): Erlbaum. p. 1–51.

Green SJ, Grorud-Colvert K, Mannix H. 2018. Uniting science and stories: perspectives on the value of storytelling for communicating science. Facets 3:164–73.

Hadzigeorgiou Y. 2016. Narrative thinking and storytelling in science education. In: Imaginative science education: the central role of imagination in science education. Switzerland: Springer International Publishing. p. 1–283.

Harari YN. 2015. Sapiens: A Brief History of Humankind. 1st ed. New York (NY): Harper.

Hasson U, Landesman O, Knappmeyer B, Vallines I, Rubin N, Heeger DJ. 2008. Neurocinematics: the neuroscience of film. Projections 2:1–26.

Head JJ, Bloch JI, Hastings AK, Bourque JR, Cadena EA, Herrera FA, David Polly P, Jaramillo CA. 2009. Giant boid snake from the Palaeocene neotropics reveals hotter past equatorial temperatures. Nature 457:715–8.

Head JJ, Gunnell GF, Holroyd PA, Hutchison JH, Ciochon RL. 2013. Giant lizards occupied herbivorous mammalian ecospace during the Paleogene greenhouse in Southeast Asia. Proc Biol Sci 280:20130665.

Hofmeister JKK. 2015. Movement, abundance patterns, and foraging ecology of the California two spot octopus, *Octopus bimaculatus* [doctoral dissertation]. Department of Integrative Biology: University of California, Berkeley.

Hühn P, Schmid W, Schönert J (eds.). 2009. Point of view, perspective, and focalization: modeling mediation in narrative. Berlin: Walter de Gruyter.

Illingworth S. 2017. Delivering effective science communication: advice from a professional science communicator. Semin Cell Dev Biol 70:10–6.

Jensen P, Rouquier J-B, Kreimer P, Croissant Y. 2008. Scientists who engage with society perform better academically. Sci Public Policy 35:527–41.

Kahneman D. 2011. Thinking, fast and slow. New York (NY): Farrar, Straus, and Giroux.

Katz Y. 2013. Against storytelling of scientific results. Nat Methods 10:1045.

Kuehne LM, Twardochleb LA, Fritschie KJ, Mims MC, Lawrence DJ, Gibson PP, Stewart-Koster B, Olden JD. 2014. Practical science communication strategies for graduate students. Conserv Biol 28:1225–35.

Loverd R, ElShafie SJ, Merchant A, Gerbin CS. 2018. The story of the science & entertainment exchange, a program of the national academy of sciences. Integr Comp Biol.

Lubchenco J. 1998. Entering the century of the environment: a new social contract for science. Science 279:491–7.

Lucas G. 1977. Star Wars. USA: 20th Century Fox.

Luna RE. 2013. The art of scientific storytelling: transform your research manuscript, using a step-by-step formula. Amado International.

Martinez-Conde S. 2016. Has contemporary academia outgrown the Carl Sagan effect? J Neurosci 36:2077–82.

Martinez-Conde S, Macknik SL. 2017. Opinion: finding the plot in science storytelling in hopes of enhancing science communication. Proc Natl Acad Sci U S A 114:8127–9.

Mazurkewich K. 2018. Technical experts need to get better at telling stories. Harvard Business Review (https://hbr.org/2018/04/technical-experts-need-to-get-better-at-telling-stories).

McKee R. 2010. Story: style, structure, substance, and the principles of screenwriting. 1st ed. Harper Collins.

Merriam Webster. 2015. Merriam Webster. Online dictionary.

National Academy of Sciences. 2014. The science of science communication II: summary of a colloquium. Washington (DC): The National Academies Press.

National Academy of Sciences. 2017a. Communicating science effectively: a research agenda. Washington (DC): The National Academies Press.

National Academy of Sciences. 2017b. Using narrative and data to communicate the value of science: proceedings of a workshop—in brief. Washington (DC): The National Academies Press.

National Academy of Sciences. 2018. The science of science communication III: inspiring novel collaborations and building capacity: proceedings of a colloquium. Washington (DC): The National Academies Press.

National Science Board. 2012. Science and technology: Public attitudes and understanding. In: Science and Engineering Indicators 2012. Arlington (VA): National Science Foundation. p. 7-1 to 7-51.

National Science Foundation. 2002. Merit review broader impacts criterion: representative activities (https://www.nsf.gov/pubs/2002/nsf022/bicexamples.pdf).

Nisbet MC, Scheufele DA. 2009. What's next for science communication? Promising directions and lingering distractions. Am J Bot 96:1767–78.

Norris SP, Guilbert SM, Smith ML, Hakimelahi S, Phillips LM. 2005. A theoretical framework for narrative explanation in science. Sci Educ 89:535–63.

Olson R. 2009. Don't be such a scientist: talking substance in an age of style. Washington (DC): Island Press.

Olson R. 2015. Houston, we have a narrative: why science needs story. Chicago (IL): University of Chicago Press.

Olson R, Barton D, Palermo B. 2013. Connection: Hollywood storytelling meets critical thinking. Los Angeles (CA): Prairie Starfish Productions.

Oxford English Dictionary. 2017. Oxford English dictionary online. Oxford English Dictionary.

Padian K. 2018. Narrative and "anti-narrative" in science: how scientists tell stories, and don't. Integr Comp Biol published online (doi: 10.1093/icb/icy038).

Peyton B. 2018. Rampage. USA: Warner Bros. Pictures and New Line Cinema.

Pixar Animation Studios. 2017. Pixar in a box: the art of storytelling. Khan Academy (https://www.khanacademy.org/partner-content/pixar/storytelling).

Propp V. 1925. Morphology of a folktale. Austin (TX): University of Texas Press.

Rather D. 2017. A return to reason. American Geophysical Union Fall Meeting at the Ernst Morial Convention Center, New Orleans, Louisiana.

Russo G. 2010. Outreach: meet the press. Nature 468:465–7.

Sachs J. 2012. Winning the story wars: why those who tell—and live—the best stories will rule the future. Boston (MA): Harvard Business Review Press.

Sanford AJ, Emmott C. 2012. Narrative and the rhetorical processing framework. In: Mind, brain and narrative. 1st ed. New York (NY): Cambridge University Press. p. 1–8.

Schank R, Abelson R. 1995. Knowledge and memory: the real story. In: Wyer RS Jr, editor. Knowledge and memory: the real story. Lawrence Erlbaum Associates. p. 1–85.

Schimel J. 2012. Writing science: how to write papers that get cited and proposals that get funded. New York (NY): Oxford University Press.

Scott R. 1982. Blade runner. USA: Warner Bros. Pictures.

Simmons A. 2001. The story factor: inspiration, influence, and persuasion through the art of storytelling. New York (NY): Basic Books.

Stephens GJ, Silbert LJ, Hasson U. 2010. Speaker–listener neural coupling underlies successful communication. Proc Natl Acad Sci U S A 107:14425–30.

Sternberg SH, Redding S, Jinek M, Greene EC, Doudna JA. 2014. DNA interrogation by the CRISPR RNA-guided endonuclease Cas9. Nature 507:62.

Vogler C. 2007. The writer's journey: mythic structure for writers. Studio City (CA): Michael Wiese Productions.

Zak PJ. 2015. Why inspiring stories make us react: the neuroscience of narrative. Cerebrum 2015:2–13.

Zak PJ, Kurzban R, Matzner WT. 2004. The neurobiology of trust. Ann N Y Acad Sci 1032:224–7.

Zak PJ, Stanton AA, Ahmadi S. 2007. Oxytocin increases generosity in humans. PLoS One 2:e1128.