To Teach Science, Tell Stories

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Abstract

The narrative is a fundamental, ubiquitous mode of human communication. A story — an account of events with emphasis on personal perspective or connection, employing dramatic tension — is among the most widespread and common methods of communicating information. Stories strengthen the social bonds of human society and facilitate the transmission of culture. We learn about our world by hearing and seeing stories, and in turn we share our understanding of the world by telling stories. Neuroscience research supports the importance of narratives to human culture. Stories activate neurochemical pathways related to trust and social bonding, and the emotional resonance evoked by a narrative stimulates neural systems related to empathy.

Education has long made use of the story as a pedagogic technique. Evidence is building that not only is a story innately interesting and compelling, but that use of this technique stimulates learning and recall. Teachers of humanities have widely embraced the value of teaching with stories. Although science teachers have been hesitant to adopt this technique, research indicates storytelling and related use of narrative is effective in promoting the understanding and acceptance of science concepts. There are a wide range of narrative teaching techniques that can be used in a science classroom, involving involve both teacher and student as storyteller.
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Introduction

The telling of stories as a primary method of communicating ideas is considered to be universal, or nearly so, among human societies, and educators have seized on narratives and storytelling as valuable pedagogical tools. Teachers of young students have long understood the power of a story to engage and teach, and this technique is increasingly common among those who teach students of all ages. However, although language arts, social studies, and history teachers have long embraced this technique in all its variety, educators in the sciences have been less willing to accept it. What we consider “stories” have seemed less rigorous and more frivolous, thus less relevant to conveying the complex ideas and techniques taught in the sciences. Contrary to this view, I propose that the use of narrative, in a variety of forms and formats, can be a powerful pedagogic tool to help students comprehend and learn the concepts of science. In this exploration of the use of storytelling, I will explore the history of its use, the biological effects that make narrative stories so powerful, and the use of such stories in educational settings. I will also examine specifically how storytelling is being used in the science classroom, what the pedagogical research shows about its effectiveness in those situations, and provide examples of how narratives and stories can be used in specific situations.

It is important to ground this discussion in an understanding of how the concepts of science have traditionally been taught: as a sequence of facts supporting a concept or idea, building upon similarly constructed sequences, and resulting in the “big ideas” of scientific thought such as the structure of matter or biological evolution. This pedagogy is not unreasonable. Indeed, it is based on the way in which we have looked at and come to
understand the natural world – that is, fact by fact, each building upon the next, resulting in an increasingly complex and nuanced understanding of the world. As Isaac Newton wrote in a letter to his rival Robert Hooke in 1675, “If I have seen further it is by standing on the shoulders of Giants.” This progressive and cumulative process, developed over the last five centuries – what we can call “scientific method” – is indisputably at the heart of scientific inquiry. This process is fundamental to the education of students as they learn to investigate the natural world. But narrative pedagogy and rigorous scientific education are not mutually exclusive. Indeed, Nobel Prize winning chemist and philosopher Roald Hoffmann observes that science is “messier” than many may think, and that telling that story can be very compelling: “Because narrative is not reducible to mathematics, it is not given its due in our scientific world. Too bad; storytelling is both ancient and deeply human. It is a shared treasure between science and the arts and humanities” (Hoffman, 2014, p. 250). Particularly when the subject material is politically polarizing, storytelling as opposed to fact-telling may be particularly effective. Research shows that increasing scientific knowledge often reinforces controversial viewpoints while stories can “build bridges of mutual understanding” (Foley and Arena, 2017).

I will argue that science education can greatly benefit from the use of narrative techniques more often associated with the humanities. Science teachers can effectively teach complex concepts by reframing scientific discoveries as dramatic narratives or having students generate their own narratives to explain ideas. Educators can engage students through the study of novels, fictional stories, and myths. Teachers can draw from personal experience to enhance their lectures and explanations. Students can generate videos, graphic novels and
written and oral stories as formative or summative assessments of their learning. A wide range of strategies exist that allow both educators and students to learn and teach by telling stories.
Telling Stories

The story – from *Rapunzel* to *War and Peace* – is one of the basic tools invented by the human mind, for the purpose of gaining understanding. There have been great societies that did not use the wheel, but there have been no societies that did not tell stories.

Ursula K. Le Guin (1979, p. 30)

The prehistoric bison shrugged as the flickering light swept across its massive shoulder. Nearby, a group of horses, a large stallion guarding his mares, warily faced a lion. A ruddy, wooly rhinoceros and a shaggy mammoth stood unconcerned not far away. I stood breathless, watching them in awe. Although long gone from the rolling hills of southwestern France, these animals were real to me. I watched as they seemed to move, deep within the Font-de-Gaume cave in the French province of Dordogne, between the Loire valley and the rugged Pyrenees Mountains. As I crouched in the narrow corridor in the cave and our guide swept his flashlight across the walls, these animals seemed vividly alive. I wanted to touch them, to connect with the people who had drawn them 19,000 years ago. It took all my will power not to reach out when the guide wasn’t looking.

This winding cavern is not far from the Lascaux caves, home of the world’s best known Upper Paleolithic cave paintings. Like those in its more famous neighbor, these animals are drawn with black charcoal and red ocher on the buff walls of the cave (Daubisse, 1994). Unlike
Lascaux, it’s still possible to walk through this cave and see firsthand the depictions of the animals, more than 200 of them – a herd of reindeer with the bison, an ibex, a cave bear. There is a spectacular film by Werner Herzog called *Cave of Forgotten Dreams* that gives a gorgeous look at some of the oldest of France’s cave paintings. Herzog had to get special dispensation from the French Minister of Culture to take his small film crew inside the Chauvet caves, all of them wearing special suits and shoes, and allowed them to film only a few hours each day in order to protect the precious drawings not only from a possible human touch, but even from their breath. Similarly, the Lascaux paintings are off limits to almost everyone. But Font-de-Gaume, discovered in 1901, is still open, though allowing fewer than two hundred visitors a day. Our group of a dozen walked single file through the narrow corridors, sometimes stooping to squeeze through a claustrophobically narrow section.

What is not apparent before seeing these paintings in person is just how astonishingly realistic they are (Daubisse, 1994; Cloughly, 2002). The animals from the Font de Gaume cave are iconic: these animals are highlighted in one of the striking Charles Knight murals in the American Museum of Natural History in New York City (Clough 2002). They are not primitive sketches scratched with burnt stick or daubed on the wall with a finger smeared in red clay. They are breathtakingly lifelike. One cannot help but feel the humanity of the people who painted them. Also, the artists did not simply paint as if on a blank canvas. They made use of the walls’ natural curves and irregularities, using them to highlight shoulders or other parts of the animals so that as the light moved, and with it the shadows of these cave textures, the animals seemed to shift and move, to come alive. These are the first moving pictures. In that small space, I could get a glimpse of what it must have looked like to create these images in the
flickering light of a simple animal fat lamp or pitch torch (Leroi-Gourhan, 1982), what it might
have smelled like, how it felt to squeeze deep into the cave and find blank canvas for my ideas.
We do not know why they painted these particular animals. Were they tribal totems or
attempts to capture the spirits of these powerful animals? Do they somehow record the change
of seasons or migrations? Were they the product of a human need to express awe? They are
certainly awe inspiring and one cannot help but almost hear these images echoing as stories
(Jueds, 2005). I realized that every time I breathed out, the carbon dioxide and the moisture in
my breath took a tiny toll on the paintings. I like to think that a few atoms of my breath mingled
with and joined those of the individual who painted them nearly twenty millennia before. The
archaeological record shows us that our species has been creating “stories” such as the ones
told on the walls of this cave for at least forty thousand years, the age of dated pigments on the
walls of caves in Spain and Indonesia (Wilford, 2014).

Creation stories, accounts of how the world and its people came into existence, are
probably the earliest written and oral human narratives. These stories arose in almost every
religious tradition in all parts for the world (Sproul, 1991). Babylonian and Sumerian creation
myths are themes of conflict and resolution, all elements considered crucial to effective and
powerful narratives. The Babylonian story, inscribed on clay tablets, has been dated to the early
part of the second millennium BCE. Greek myths date to the first millennium BCE, in both
written and pictorial form, and still delight children today. The Abrahamic religions share
creation stories of chaos and darkness becoming order and light that are of similar age and
clearly still resonate with adherents of those three major faith traditions. Icelandic manuscripts
from the 13th century CE tell the Norse story of how the current world and its people came into
being from chaos (Willis, 2006). Although varying in detail, these foundational stories feature a
dynamic narrative and plot, compelling characters, and meaning and impact beyond the basic
facts.

Throughout history, cultures have revered those individuals who carried a culture’s
stories and oral history. From Homeric epics to the griots of Africa, the shaman of the Navaho,
the troubadours of medieval France, to the travelling actors of Shakespeare’s age, these
that our penchant for storytelling runs deep in the human psyche. Indeed, he argues, we might
as well be named *Homo fictus*, or “fiction man.”

Tens of thousands of years ago, when the human mind was young and our numbers
were few, we were telling one another stories. And now, tens of thousands of years
later, when our species teems across the globe, most of us still hew strongly to myths
about the origins of things, and we still thrill to an astonishing multitude of fictions on
pages, on stages, and on screens – murder stories, sex stories, war stories, conspiracy
stories, true stories and false. We are, as a species, addicted to stories (p. viii)

Today, we tell stories to our children to comfort them when we put them to bed. We
grumble when we hear our own parents begin, “When I was a child...” At work we give
presentations to share our ideas. We are immersed in advertisements trying to convince us to
buy a product by telling a story. We love music, and the most compelling songs bring us into
their stories and move us to tears. We are inspired by TED Talks and the personal stories of
triumph and tribulation we hear on *The Moth Radio Hour*. Millions play online role-playing games that lead to sprawling, interactive worlds of the imagination, and result in the creation of digital communities and social organization that can feel as real as the physical world. We make elaborate costumes to sit in darkened theaters with fellow fans to watch the latest Star Wars movie, and our thirst for compelling stories drives a television and online industry that creates more programming than we could possibly view in a lifetime of binge watching. We are immersed in stories.

Given how significant and ubiquitous the story is to human culture and how long we have been telling stories, we can wonder if this trait represents an evolutionary adaptation that helped *Homo sapiens* succeed? Although the ability to tell stories and the need to hear them is universal, it does not follow necessarily that this is an evolutionary adaptation; it could be a behavior that emerged coincident with the development of culture. But, as Mellman (2012) observes, storytelling is also unique to our species; although other animal species show what can be considered to be characteristics of culture, such as learned behavior and distinct traits in different communities, there is no evidence that other animals, primates or not, have any conception of “telling stories.” And verbal storytelling depends on symbolic language, a trait that seems unique to human beings. Furthermore, “storytelling seems to be a notably self-rewarding activity...that seems to occur on a wider scale than would seem justified by rational choice” (p. 30). Thus the fact that storytelling is so common “might indeed be revealing of an innate preference for this behavior (p. 31). The propensity of humans to tell stories may be hard-wired into our minds.
The Biological Basis of Storytelling

Nature designed us to enjoy stories so we would get the benefit of practice. Fiction is an ancient virtual reality technology that specializes in simulating human problems.

Jonathan Gottschall (2012, p. 59)

Humans have been storytellers for tens of thousands of years. Indeed, historian Yuval Harari thinks this practice goes back 70,000 years, when the human cognitive revolution began. Our ancestors invented bows and arrows, boats, oil lamps, art – painting and sculpture – even the apparent concept of an afterlife or spirituality, in the roughly 40,000 years after we exploded out of Africa. What sparked this socially incendiary expansion? Many researchers, including historian Yuval Harari, hypothesize it was a mutation in our brain’s neural circuitry that allowed us to think in the abstract and, most importantly, to communicate and cooperate across large groups. Harari calls it the “Tree of Knowledge mutation” and says the ability to think in the abstract has hardwired humans to use stories (Harari, 2015a, p. 21). In a 2015 TED Talk, Harari noted that many animals can describe reality to others in their group. For instance, he said, chimpanzees can inform others where a predator is hiding or where food can be located. What they cannot do is to imagine an abstract idea and convey it to others.

Humans use their language not merely to describe reality, but also to create new realities – fictional realities. A human can say, "Look, there is a god above the clouds!"
And if you don't do what I tell you to do, when you die, God will punish you and send you to hell." And if you all believe this story that I've invented, then you will follow the same norms and laws and values, and you can cooperate. This is something only humans can do. (Harari, 2015b, 07:45).

Storytelling seems to be a universal human activity. From tales of battles told around a fire to multi-million dollar blockbuster movies, from stories that lull children to sleep to lies about “the one that got away,” we tell stories throughout our days and throughout our lives. Not only is it universal to human beings but it is also unique to our species, so far as we know. Symbolic language, the vehicle through which our stories are expressed, is also a uniquely human capability (Mellman, 2012). As such, does storytelling have a biological basis? Does the ability to create a story confer an evolutionary survival advantage in human beings? Is this why the desire to tell stories and the power of hearing them is so widespread among Homo sapiens? I will argue that the answer to all these questions is Yes.

There is no doubt that a compelling story can have a powerful impact. Even the most unsentimental among us has been moved by a novel, movie, or song. Creation stories such as found in Genesis, epic tales of Medieval chivalry or Samurai glory – across time and cultures, humans have gone to war and fallen in love because of stories. The half-trillion dollar global advertising industry (Total Media, 2016) centers on creating stories that are emotionally resonant to those who see, hear, or read them, and who will then be moved to buy the product. Why do these stories have such a hold on us?
As it is with almost all scientific discoveries, this one begins with a story. In a professional journal article, neuroscientist Paul Zak recounted his experience on an overnight cross-country flight home to California after a trip to Washington, D.C.

Tired and unable to bang on my laptop in the turbulence at 40,000 feet, I decided to watch Million Dollar Baby. I hadn’t seen it, but I figured a Clint Eastwood-directed film that has won the Oscar for Best Picture would be a deserved break for a hard week. It is a wonderful film, and I became deeply absorbed in it. The narrative is circumscribed by a father-daughter story and concludes with an agonizing act. When the movie was over, the man next to me said, “Sir, is there something I can do to help you?” I was crying. Well, not really crying, more like heaving big sloppy sobs out of my eyes and nose and mouth. Everyone around could hear me but I could not suppress my sadness (2015, p. 2)

Zak investigates behavioral neurochemistry. He realized that this film experience was so powerful that it fooled his mind into reacting as if he was personally experiencing the story, and with it, the suffering of his own daughter. Key to this emotional response is the neurochemical oxytocin.

Oxytocin is a hormone produced in the hypothalamus, a small section of the brain just above the brainstem. Every animal with a backbone has a hypothalamus. In humans, it’s the size of an almond, a small bit of brain tissue that controls hunger and thirst, sleep patterns, and how we connect with other people. Oxytocin is produced when a woman gives birth, helping her bond with her newborn child, and is released as she nurses that child. It also plays a role in
sexual attraction and pair bonding, and in how we recognize others and form relationships with them. It moderates aggression and is produced when we are shown kindness by others. Zak calls it “the substrate for the Golden Rule: If you treat me well, in most cases my brain will synthesize oxytocin and this will motivate me to treat you well in return” (2015 p.3). This neurochemical has been shown to mediate social trust and empathy (Kosfeld et al., 2005). In short, oxytocin mediates much of the behavior that allows us to be socially successful primates (Lee et al., 2009). Zak, whose lab discovered this connection, says oxytocin is the chemical that tells our brains that it’s safe to approach someone else (Zak, 2014). What does this have to do with telling stories? Zak has shown that when we hear a compelling story, it stimulates the production of oxytocin in our brains, and in turn, all the cascading effects this hormone facilitates (Zak, 2015). Zak’s study found this effect in videotaped stories as well as those directly told by one individual to another. But not just any story – it must be a story with a strong character with whom we can identify, and with the dramatic tension necessary to sustain the mind’s attention. When those two factors are present we “will come to share the emotions of the characters in it, and after it ends, likely to continue mimicking the feelings and behaviors of those characters” (Zak, 2014). So, when we walk away after watching a tense, dramatic movie, Zak says we not only feel the effects of the adrenaline produced by the excitement of the story, but also that of oxytocin, as empathy for the character with whom we identify. It is not just a two-hour movie seen in a darkened theater with thundering sound that generates this chemical rush. Any story, heard, seen, or read has the potential to facilitate the release of oxytocin. Zak says his research indicates that these stories, and their emotional impact, result in better understanding of the important ideas associated with the story and
better recall of those ideas weeks later. “When you want to motivate, persuade, or be remembered, start with a story of human struggle and eventual triumph. It will capture people’s hearts – by first attracting their brains” (Zak, 2014).

In addition to the oxytocin response, another characteristic of the brain may also allow us to experience stories vicariously. In the 1990s Italian neuroscience researchers, investigating the parts of the brain associated with hand, eye, and mouth coordination – the neurons that let us, for example, reach out and pick an apple from a tree – made a serendipitous discovery. The same pathways that allowed the monkeys to reach out and pick up a raisin also were activated when they saw another monkey reach and pick up the raisin (Rizzolatti et al., 1996). These pathways, now identified as “mirror neurons” for the way they allow us to mirror or reflect internally what we see externally, seem do much more than help monkeys find and eat treats. Since this discovery, researchers have found evidence of neural pathways that both control an action and respond to seeing the same action in many parts of monkey brains. Functional magnetic resonance imaging evidence strongly suggests that these same pathways are not only present in human brains as well, but are widespread among primates and mammals in general. Neuroscientists think these networks of nerves are activated not only when we perform a wide range of actions and see others do the same thing, but also when we feel emotions and when we see others feeling them (Keysers, 2010; Gottschall, 2012). The activity of these mirror neurons may be what allows us to emotionally and physically experience a story. Neuroscientist Marco Iacoboni argues that movies feel real to us because the mirror neurons in our brains vicariously recreate in our minds what we see on the screen.
Why do we give ourselves over to emotion during the carefully crafted, heartrending scenes in certain movies? Because mirror neurons in our brains re-create for us the distress we see on the screen. We have empathy for the fictional characters – we know what they’re feeling – because we literally experience the same feelings ourselves. And when we watch the movie stars kiss on screen? Some of the cells firing in our brain are the same ones that fire when we kiss our lovers (Iacoboni, 2008, p. 4).

It is not just pleasurable situations that provide evidence of these neural pathways. Dutch researchers placed volunteers in a functional MRI machine in order to watch how their brains reacted to stimuli triggering disgust. Investigators created three situations for the subject. First they showed them a film clip of an actor grimacing in disgust after drinking a liquid. Second they had the subjects themselves drink a bitter, disgusting tasting liquid. Finally, the neuroscientists read aloud short scenarios, asking the subjects to imagine horrifying scenarios involving disgust.1 In all three cases, brain scans showed that same region of the brain was activated, indicating that the same neural pathways were triggered by the experiences, whether observational, personal, or imaginative. The researchers concluded that we can “achieve vivid emotional feeling states in the absence of actual emotional encounters in a myriad of ways, including the recall of past experiences, the imagination of hypothetical experiences, reading a good book, watching a good movie or witnessing a friend’s experience” (Jabbi et al., 2008, p. 7). We can accurately empathize with another person because

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1The scenarios including having the subjects imagine wiping their faces with a towel only to find it covered in cat feces or rolling over in bed while sleeping in decrepit inn to find a rotting dead rat on the pillow and experience “the horrid taste of tainted blood entering your mouth.”
the same parts of the brain that are used to perform an action or experience an emotion are also triggered when we imagine that stimulus. The firing of our neurons in response to a story’s stimuli strengthens the neural pathways that allow us to solve social problems and interact with others.

If these neural characteristics indeed allow us respond to an imagined event as if we were experiencing it firsthand, how can we explain the evolution of this trait? What advantage did these emotive responses give our early ancestors? Gottschall argues that this ability prepared us to cope with the social structures that a growing population faced. He calls this the “problem simulation theory.” Storytelling, he argues, “is a powerful and ancient virtual reality technology that simulates the big dilemmas of human life” (2012 p.67). We respond to stories so innately and so vividly because that response allowed our ancestors to practice key social skills – cooperation, coordination, leadership, conflict resolution – necessary to survive in an increasingly complicated culture. Just as a flight simulator allows a pilot to practice emergency maneuvers without risk of life, that deeply personal response to stories allowed human beings to try out – to feel and experience – social interactions without the danger of being attacked because of an offense. In the case of a pilot, it is not that flying a plane on the level in a clear sky is terribly difficult – beginners can take the controls on their first flight. But if an emergency arises, say landing during a sudden thunderstorm after an engine fails, there may be a different and disastrous outcome. Using a flight simulator, the neophyte pilot can crash again and again until she learns how to control her fear and juggle the plane’s systems and controls. The same can be said of learning how to experience life.
Cognitive scientist Keith Oatley agrees that stories are “the mind’s flight simulator” (2008, p. 1030), allowing us to rehearse the dangerous situations we may face in life without their inherent risks. Oatley found that active readers of fiction exhibited greater empathy and more accurate interpersonal perception, as measured on standard psychological tests, than those who read nonfiction (Oatley, 2008, 2012). In further studies, they found this was not because empathetic people are drawn to fictional stories, but that empathy seemed to be the result of reading these stories. Comparing a short story by Anton Chekhov with a control text written in a documentary form and stripped of emotional context, they found greater empathy expressed by those reading the former. Oatley speculates that perhaps this is due to how we identify with the characters of a story. Regardless, he says, stories can help us understand and navigate the complexities of social life. Ohio State University narrative studies professor David Herman calls the story a “cognitive structure for way of making sense of experience” (Herman, p. 7).

When we interact mentally with a story’s characters, we identify and empathize with them. Our brains, because of the mirror neuron phenomenon, tell us that what is happening to them is happening to us as well. When neurons fire in response to the stimulus of a compelling story, the strengthened neural networks prepare us to navigate life. We are truly a story-telling and story-seeking species, Homo narrativus, as some observers have dubbed us (Dodds, 2013). As we try to make sense of the world we see narratives and stories – meaning – everywhere we look.
This is an active field of neuroscience research and while many investigators are confident that mirror neurons explain how we form bonds with others, it remains controversial. Nonetheless, it seems clear that stories affect our brains physiologically.
What is a story?

“Somebody gets into trouble and gets out of it again. People love that story!
They never get sick of it.”

Kurt Vonnegut (1997, 01:25)

What are the elements of a story? That is, what makes a recitation of facts or events into a “story?” Storytelling consultant and author Annette Simmons says it is “a reimagined experience narrated with enough detail and feeling to cause your listeners’ imaginations to experience it as real” (2007, p. 19). As we have seen, the stimulation of imagination and empathy activate certain neural pathways. How do we compose or structure a story so as to most effectively trigger those circuits of the mind? I propose that in order tell a story successfully it is important to understand the structure of an effective and affective story. We can analyze a narrative story from three perspectives: the structure and composition of the story itself, the context in which the story is told, and the medium through which it is conveyed.

The Structure of the Story

A story involves a narrative, characters, a setting, anda point of view or perspective. When considering how to use storytelling in a classroom, it is helpful to consider all four of these elements. In a nonfiction story, the narrative, setting, and characters are generally and in large part predetermined. However, the point of view of the story can be manipulated to make it more compelling.
Writing instructors emphasize the power of the “story arc,” the template for dramatic writing. This is the narrative movement of the story – the chain of events from beginning to end. Although in a nonfiction setting the events generally are not invented, the way in which they are selected and organized is certainly within the storyteller’s control. While, different sources suggest somewhat different frameworks, this format has three essential parts: a beginning that sets the scene and explains the characters of the story; a middle in which the tension builds, the action rises, and the characters face conflict and challenge; and the end, a culmination that portrays the resolution of this conflict, how the characters have changed, and what they have learned. Some instructors are more specific, charting a series of rising and falling conflicts and challenges leading ultimately to resolution. Watts (2012) begins with the “stasis” in which the story is set, followed by the “trigger” that sparks the story, the quest to regain stasis, the obstacles, conflict and trouble the protagonist faces, all of which lead to critical decisions that develops the character. Then follows the climax of the dramatic tension and action, a reversal of fortune, and finally, a resolution leading to a new level of the characters’ understanding of their situation and a return to new level of stasis. Regardless of the specifics, a compelling story follows a certain path from beginning to end.

Novelist Kurt Vonnegut, in a recorded lecture, argued that the best form of a story is the simplest – for example, “boy meets girl,” in which the main character finds something wonderful, loses it, then regains it; or “man in a hole,” in which the protagonist gets into trouble, gets out of it, and learns a valuable lesson (1997). Most stories follow a simple template, according to Vonnegut. Indeed, he argued, the dramatic arc of most stories aresimple
enough that they can be drawn on a graph.² Vonnegut graphed stories on two axes: the horizontal, from the beginning to the end of the story, and the vertical, from ill fortune to great fortune. To Vonnegut, the most interesting shape was that of the Cinderella story. From a modest beginning, her fortune rises to a high point when, at the stroke of midnight, she loses everything in a reversal of fortune. Before long, though, she regains her good fortune and lives happily ever after. Vonnegut noted that this story form applies to a wide range of powerful narratives, and even “looks like the creation myth of virtually every society on earth” (p. 288).

In Vonnegut’s lecture, he observed that “there is no reason why the simple shapes of stories can’t be fed into computers – they are beautiful shapes” (1997, 00:23). Two decades later, a group of computer scientists and mathematicians did just that. Analyzing 1,327 stories, they found “a set of six core emotional arcs which form the essential building blocks of complex stories.

²Vonnegut called this idea his “prettiest contribution to his culture,” one he outlined in a master’s thesis in anthropology for the University of Chicago (Vonnegut, 1984, p.285). Fortunately for fans of quirky and imaginative speculative fiction, Vonnegut said the thesis was rejected as being too simple and “too much fun,” precluding a career as an anthropologist.
emotional trajectories (Reagan et al., 2016). The researchers, from the University of Vermont and the University of Adelaide, also analyzed the most popular types of stories, measured by how many times the six different narrative arcs were downloaded via Project Gutenberg, an online archive of public domain stories. Plot and narrative structure, they found, were less factors in popularity than having a complex emotional arc. And more to the point, the basic narrative structure they identified as most popular was the same as the structure Vonnegut noted was most powerful; successful stories are dynamic, involving rising and falling action and fortune. The most successful, emotionally resonant stories follow the formula of rising-falling-rising action/fortune, or falling-rising-falling-rising action/fortune.

Secondly, in addition to a story’s narrative arc, its characters are crucial to success. The protagonist and other characters interact with the situations and chain of events and with each other, but also with the listener, reader, or viewer. The characters drive the story and provide greater meaning to us than facts alone. Their experience – their personal story arc – is what connects us to them. In order to activate the brain’s emotional reflexes, the reader/listener/viewer must make a personal connection to the character. Again, the primary character of a nonfiction story is often set, but the description and detail included are flexible.

Thirdly, the setting of a nonfiction story is usually constrained by reality, but, as with the traits of the characters, the choice of detail is up to the storyteller. Vivid descriptions can evoke a strong visual image in listeners, adding to the emotional impact of the story.

Finally, we can consider the point of view reflected in the story. Collins writes that “truly influential storytelling come from the ability to step in and out of different points of view” (Collins, 2007, p. 195). She argues that the goal of effective storytelling must be to deliberately
seem less objective and more personal, as it is the personal connection generates empathy, acceptance, and understanding. I do not propose abandoning objectivity in telling science stories, but Collins’ point about the emotional connection to an audience is persuasive. In fact, recent research finds that, particularly when dealing with culturally controversial issues such as climate change and human evolution, providing more information tends to be polarizing rather than enlightening. The investigators found that even people with strong reasoning skills were more likely to stick to preconceived notions despite evidence that clearly contradicted their positions. They did not use the new information to further inform their position, they used it instead to support the answer they already supported (Klein, 2014; Kahan et al., 2013). In the case of divisive issues, telling a story would be more convincing that the data alone.

As we consider the essence of a story, it become clearer that its form is less important than its impact. Anthropologist Michael Carrithers describes a story as “characters with their relationships...set in a flow of events, a plot, with its sense of plans, situations, acts and outcomes...By means of stories humans recognize not just thoughts and not just situations, but the metamorphosis of thoughts and situations in a flow of action” (in Knox, 1997, p. 389). Ultimately, a story is an intellectual and emotional transaction between two parties, the story-teller and the story-listener, each of them bringing a distinct, unique background and view of the world to their interpretations of the story.
The Context of the Story

As we can classify stories by form, we can also organize them by the situation in which they are told, considering stories from the perspective of the setting, the number of listeners, and element of preparation. Using these three perspectives, McDrury and Alterio (2001) identify eight pathways storytelling can take, noting that “different pathways lead to different outcomes” (p. 63). They argue that by making choices about which pathway to use, educators can decide which storytelling mechanism best meets their needs in a particular situation. Understanding the consequences and impact of various pathways allows storytellers to maximize the value of reflective learning, the process of reconsidering a story in order to deepen its impact.

The setting in which a story is told may be formal or informal. Formal sessions are planned in advance and even rehearsed. This allows the storyteller to consciously include certain parts of the story and arrange them in a particular way. Such storytelling can be part of a classroom presentation or a segment of peer to peer interaction, and can involve teachers, students, or both. Informal storytelling happens in a spontaneous manner, when and wherever there is someone telling the story to a willing listener. As an example, the story may be told at a social gathering. It is not rehearsed, although the storyteller may be familiar with the story. In either case, the listeners, those interacting with the storyteller, may respond by reflecting the story, by asking questions, or by offering their own stories. Particularly in the informal situation such give-and-take is common.

The number of listeners also shapes the storytelling process and affects the outcome. Having a greater number of listeners allows the story to be experienced from different
perspectives. The audience, in their response, will be more diverse and is likely to “uncover new and possibly totally unexpected insights” (p.65). The response of a single listener, conversely, may focus the original story more sharply by increasing the level of dialogue – rather than a wide array of responses, the questioning may bring to light greater depth.

It is worth noting that listeners play a distinct and important role in the storytelling process. Education researchers Janice McDrury and Maxine Alterio note that listeners can be passive or active. In the former, if listeners focus primarily on the teller’s story, as often happens in a standard classroom teaching situation, the interaction is primarily one way and allows the teller to explain in detail. McDrury and Alterio call this the “response discourse.” On the other hand, if listeners actively respond and engage in a “response story,” the focus shifts to a dialogue and becomes a shared experience. While both parties are active in this interchange, the focus may be wider than in the case of the former, mostly-one way exchange.

Finally, the storyteller’s preparation for the story can be either spontaneous or formal. A formally told story requires preparation, planning, and likely practice. Pre-determined storytelling is more likely to result in reflective learning, the process of stepping back from a classroom experience, then reconsidering and analyzing it. It is important to recognize that both the teller and the listener benefit from this interchange of ideas, regardless of the form. The storyteller both conveys the narrative and, in receiving the response, deepens his/her understanding. The listener, through active engagement with the story, does the same. The value to analyzing a story through these parameters – setting, listeners, and type – is that we can understand how to use narrative storytelling most advantageously. One could also choose different pathways to tell the same story, in order to achieve differing outcomes.
McDrury and Alterio define eight distinct storytelling pathways that result from the interaction of teller and listener in the three contexts. These pathways are summarized below in different combinations of setting and number of listeners.

**Informal setting, single listener** – this pathway allows a single listener to give undivided focus to the storyteller. In an education setting, it could occur between students, between student and teacher, or between teachers. The undivided attention of the single listener has the potential to create emotional connection, and the non-public, informal context may ease anxiety and worry over making a mistake. The informal setting also allows for greater interaction between parties. An unrehearsed story, rather than one planned in advance, is most likely to be told in this situation, though the opportunity might be used as a practice session for a predetermined and rehearsed story.

**Informal setting, multiple listeners** – this pathway is most likely to involve various listeners reacting and sharing their own responses to the primary story. Given the informal setting, this situation is most common in social contexts rather than in a classroom, particularly when the story is not predetermined. However, a spontaneous story can result in joint catharsis and may be useful in solving student social conflict. If the teacher is the storyteller sharing a personal experience with students, because of the informal setting the social and emotional connection with students may be enhanced. The students may feel that listening or talking in a setting outside the formal classroom lesson more relaxed and less forced.

**Formal setting, single listener** – this pathway likely happens in the classroom, either between students, as part of a reflective process, or with the teacher as the listener, allowing
the teacher the opportunity to formatively assess understanding. If the story is spontaneous, this situation may be more comfortable, in that it is likely to feel less like a public performance and thus allow greater freedom to express ideas in an unedited form. If the story is rehearsed and told in a planned manner, the one-on-one setting may also ease discomfort and help the teller focus on the experience. Both partners will contribute in this reflective process during and after the story; if it is a rehearsed story there is the added benefit of the reflective process of composing and rehearsing the story.

Formal setting, multiple listeners - when telling a planned or predetermined story, this pathway is what many would recognize as formal storytelling, particularly when the story is predetermined and planned. The teacher is often the storyteller, but student presentations are also an example of this common context. When given the opportunity for response from listeners, this context can be a reflective process for the entire group; listeners have an opportunity to probe and clarify both their own understanding of the story and that of the storyteller. With many opportunities for reflection, consideration, and assessment, this pathway has the most potential application and impact in the classroom.

Storytelling is an exchange of ideas between teller and listener, and their roles may differ depending on circumstances. The story is presented from the storyteller’s perspective, and it is that individual’s choice as to which ideas, words, and events are included in order to achieve a particular outcome. But it is also important to be aware of the perspective – the life experience lens – through which the listener receives the story. Storytelling is truly an interactive experience.
The Medium of the Story

I began this exploration by recounting my experience with paintings on the walls of the Font-de-Gaume cave. I defined those paintings as a “story” as they so vividly bring their subjects to life. Although researchers are not certain what is being said in that story, the viewer is hard pressed to ignore the emotional impact of the paintings and not to feel the artists were saying something. While putting considerable emphasis on oral storytelling, we should not limit ourselves to the medium of the spoken voice. Linguist and semiotician Roland Barthes claims narrative is universal – “a prodigious variety of genres distributed amongst different substances – as though any material were fit to receive man’s stories” (p. 79).

The narratives of the world are numberless. Narrative is first and foremost a prodigious variety of genres... articulated language, spoken or written, fixed or moving images, gestures, and the ordered mixture of all these substances; narrative is present in myth, legend, fable, tale, novella, epic, history, tragedy, drama, comedy, mime, painting (think of Carpaccio's Saint Ursula), stained glass windows, cinema, comics, news item, conversation. Moreover, under this almost infinite diversity of forms, narrative is present in every age, in every place, in every society; it begins with the very history of mankind and there nowhere is nor has been a people without narrative...it is simply there, like life itself (p.79).
To that list we can add dance, song and music, and, lately, video games among the human constructions that attempt to connect the external experience of life and the internal imagination of it.

Having outlined this broad definition of what constitutes a story, for my purposes, in the context of teaching and understanding the ideas of science, I will conclude with one significant qualifier: the stories we tell in the science classroom must be based in objective reality. They do not necessarily have to be “true” in the strict sense of non-fiction – they could be imaginative, even speculative, but they must be at a minimum reasonable and possible, and grounded in the order and rule of the natural world. Considering that almost all stories, even those fanciful and completely fictional, are ways of making sense of the world, this does not seem a restrictive caveat.
I argue with myself, You’re telling stories and you’re supposed to be teaching. I am teaching. Storytelling is teaching.

Frank McCourt (2005, p. 26)

Teaching is most effective when educators use a wide range of strategies to reach their students and when those students are given choices in how they approach their studies (Stanford, 2003). Gardner’s Theory of Multiple Intelligences identifies eight (and maybe more) ways in which individuals learn: linguistic, spatial-visual, logical-mathematical, musical-rhythmic, body-kinesthetic, interpersonal, intrapersonal, and naturalistic (Gardner, 1983, 1999, 2011). Gardner says these various “intelligences,” or styles of learning, are present in all students, and that effective pedagogy connects to as many as possible. “The broad spectrum of students – and perhaps the society as a whole – would be better served if disciplines could be presented in a number of ways and learning could be assessed through a variety of means” (Gardner, 2011, p. 13). Storytelling engages all of these learning styles at a variety of levels. In addition, research shows that students are most effectively engaged with educational experiences that interact with their emotions as well as their intellect, as research has indicated an effectively told story can (Kyriacou, 1992; Rowcliff, 2004).

In *The Power of Story: Teaching Through Storytelling*, Rives Collins and Pamela Cooper outline the value of telling and listening to stories in the classroom. They list twelve benefits of including stories in a classroom environment, some the result of telling stories, some the result
of listening to them, and some from a convergence of the two. These benefits are important to learning in general; some are of particular value in the science classroom: enhancing students’ imagination and ability to visualize abstractions, enhancing critical and creative thinking, seeing stories as a mirror of the human experience, allowing students to interact personally and individually with adults, and developing intuition.

A story enhances students’ imagination and visualization, well beyond what the bare bones of the facts alone can convey. In the classroom, teachers want to create “signature experiences” (Hernandez, 2016), moments with a lasting and potentially transformative impact on students. A story has the potential to create this signature experience. It is not the power of the facts in the narrative that creates this effect, but the power of the listener’s mind to fill in the gaps. “The storyteller provides the skeleton,” argue Collins and Cooper, “the listener adds the ‘flesh’ of scenery, character” (1997, p.11). Given a good story, our minds enhance the narrative with the richness of detail found only in our imagination. Who among us hasn’t had what National Public Radio calls the “driveway moment,” finding a story so compelling we cannot break away? It is not the story alone that creates this compelling internal image in the listener’s mind. The storyteller must also have created a vivid internal story in her own mind, and while she may not convey to her audience all these details, Collins and Cooper argue that it is critical to being an effective storyteller to create this internal visual image.

Imagination and visualization, while intrinsically important for students to develop, are also valuable in the science classroom for another reason – the emotional resonance resulting from a rich imaginative experience has been shown to enhance memory and learning. Kalat, (1995) says the more meaningful and compelling an event is, the faster that experience is
incorporated as a memory. And, emotionally intense memories are more likely to be retained. Researcher Carole Peterson (2015) surveyed children who had been treated in an emergency room for significant injuries and found that they had “enormously good memory” even ten years after an event (Hamilton, 2014). Peterson says another factor in how well memories were retained was the degree to which the child fashioned the narrative into a coherent story that could be retold. When parents subsequently talked to children about memories of injuries and other events, researchers found that children who participated in more elaborate explanations, reframing and giving added context to the event, had greater ability to recall the event and details (Sales et al., 2003). Although some of this research is based on incidents of injury, which undoubtedly created more significant emotional impact than other events and stories, it is clear that the visceral significance of an event affects how well we remember it.

Stories can enhance creative and critical thinking, qualities of thought that are very important not only to budding student scientists but to anyone expected to navigate a complex and sometimes deceptive world. Collins and Cooper say stories that pose questions or involve unsolved puzzles are particularly useful. The authors recount telling a grisly Welsh fairy tale called “Morgan and His Pot of Brains,” about a dimwitted boy trying to make his way in a dangerous, complex world. Although the central riddle asked in the story is never answered, the tale prompts eager questions from the elementary age children hearing it, who, “perhaps, like Morgan, long to have enough sense to make their way in the world” (p.16). Hours later, the authors recount, the children are still asking questions and shouting possible solutions. While this story would not likely be appropriate in a science classroom, using the same technique with a case study of, say, environmental contamination, could easily spark the same level of
involvement and interest. The important element is to pose the questions, such as “Where did this toxin come from?” and “Who or what caused the contamination?” As I will emphasize later, the most important element is to ask questions and not answer them, prompting students to wonder about the world around them.

Stories help students imagine and empathize with the human experience. Renowned child psychologist Bruno Bettelheim said fairy tales are, at their heart, an examination of the human condition (1975). They are a way of teaching children how adults navigate the world, solve problems, and make sense of our experiences. As noted earlier, stories can be thought of as a “flight simulator” for real life. While the science teacher would not likely use the Grimm brothers’ stories as a learning narrative in the classroom, we can consider “the human condition” in this case to be the intellectual struggle to understand the natural world. We can imagine the benefit to students of considering the struggles of scientists whose vision of the world conflicted with orthodoxy. Copernicus and Galileo are the usual examples of early scientists, or natural philosophers, fighting an entrenched dogma, but history is filled with others. Among them was the renowned Greek female mathematician Hypatia, stabbed to death by an angry mob of political and religious zealots in the fifth century BCE. Another is Alfred Wegener, a German meteorologist who was the original proponent of the theory of “continental drift, the notion that the continents can move across the face of the Earth⁴. He didn’t live to see it, but his idea became today’s established paradigm of plate tectonics.

Science journalist Simon Singh, in *The Big Bang* (2004), chronicles the scientific quest to

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⁴Wegener, a meteorologist by profession, was roundly dismissed and condemned by supporters of the prevailing geological orthodoxy. To them it was evident that continents were fixed, and a mechanism to propel them had not been proposed. What, they scornfully asked, could an amateur like Wegener know about the science of geology, anyway? The mechanism was found, but not for another half century.
understand the origin of the universe. Beginning with the Greek philosopher Anaximander of Miletus, who explained the Sun as a hole in a fire-filled ring that surrounded the Earth, Singh arrives, about 500 pages later, at our current understanding of the Big Bang. In the process he tells the individual stories of Copernicus, Galileo, Einstein, Hubble and a host of other pivotal figures. He brings to life their brilliance, but also their mistakes, their foibles, and their struggles to find what they believed was the truth. It is a rich source of the human narratives that resulted in our current understanding of what is arguably the greatest question of all, a question that has been asked universally among human cultures: Where did the world come from?

Stories also allow students to interact personally and individually with adults. Collins and Cooper focused on young children, painting the image of kids crowding around a storyteller, “wanting to sit on her lap or touch her. They shout, ‘Tell us another! Tell us another!’” (1997, p.14). But the same relationship is critical to all successful teaching, regardless of age or subject. The emotional connection of a well-told story can create a bond with students. It can also encourage them to imagine themselves in similar situations, experiencing similar excitement, and spark interest in additional learning. When I first began as a teacher, inspired by my passion for understanding the natural world, my love of discovery, and my desire to share this with my students, a veteran colleague advised, “they don’t care how much you know till they know how much you care.” Research consistently supports the value of a strong bond between teacher and student (Pianta et al., 2003). Personal stories reinforce that connection. For instance, when I teach students about evolution, I illustrate a lesson on Darwin’s experiences in the Galapagos Islands with stories of my own travel there. I recount my delight at watching a finch peck at a
seed and perch on a cactus, of touching a giant tortoise’s shell, of swimming with a marine iguana and looking into its black eyes, or just wading into the surf and looking out at the seemingly boundless Pacific Ocean. And I tell them how I imagined what it must have been like for Darwin to wonder about similar observations and where those wonderings eventually led him. When teaching about fossils, I tell of being the first person to ever touch the vertebra of a 67 million year old dinosaur I helped unearth in Montana. Do these stories cement the curriculum content? As noted earlier, there is evidence that a well-told story, creating an emotional resonance in the listener’s mind, can improve memory retention. But as Collins and Cooper put it, “This story time is special. No matter what else has happened during the day, they leave with a story” (p. 14). Listening to children’s stories also allows the teacher to learn what is real to a student, what the student feels is important, and thus to know better how to enhance their learning.

Stories also can nurture a student’s intuitive ability. A well-told story does more than just convey content – it also involves and ignites emotion and feeling, which as we have noted, can promote learning and memory. Collins and Cooper define intuition as being able to sense a character’s feelings when hearing, or when telling, a story. They again stress the importance of an emotional connection between story, storyteller, and the listener. Feelings, they say, “are often negated when they are expressed. But storytelling says, Hey, it’s okay to feel...feelings are what make us human” (p.16).

We see that research indicates a strong theoretical connection between telling stories and understanding the concepts that these narratives convey. A well-told story engages student interest and attention (Fawcett and Fawcett, 2011). Even as the Internet and digital technology
have made information more accessible to students than ever before – and perhaps because in today’s intensely interconnected world the facts are so overwhelmingly available – a story is even more valuable when it allows a central idea to stand out from the surrounding informational chatter. As Daniel Pink observed in *A Whole New Mind*, “if a picture is worth a thousand words, a metaphor is worth a thousand pictures.” Pink argued we are moving from the “information age” to the “conceptual age,” a culture driven less by knowledge and data and increasingly composed of “creators and empathizers, of pattern recognizers and meaning makers” (p. 50). In this environment a compelling story is more valuable than the facts alone. As Pink implies, a story that creates a powerful mental picture of a concept, historical account, or a flash of inspiration can powerfully capture the listener’s attention. It is worth noting that narrative accounts of this particular nature are not only recognized as improving and increasing attention and interest in science (Fawcett, 2011) but investigations have demonstrated that they also help students understand and absorb the ideas that these stories illustrate.
Storytelling in the Science Classroom

Science tells some rollickin’ good stories.

Roald Hoffmann (Safir, 2015, p. 55)

The process of science, that is the way we have learned to understand and explain the natural world over the last four centuries, is based on observed evidence, rational reasoning, and experimentation. We look closely at the world, examine its details, measure it, and try to figure out what it all means. We synthesize observations and conclusions into a model and use that model to make predictions. Then we examine the world again to see if these predictions are supported (Windschitl et al., 2008; Castillo, 2013). The process seems very straightforward and logical, and overall is the way we have come to today’s understanding of the natural world. This is also the way we usually teach the results of this process – what we call the academic subject of science – to students. We begin with the facts and slowly build to theories. We frequently use the method known as inquiry-based learning to encourage students to discover the facts and ideas themselves, then to connect them together into larger ideas. Small details come into focus, then the relationship between these details, and finally they are able to make the connection to a “big idea” such as the atomic nature of matter or biological evolution. Thus the process of teaching science recapitulates the historical process of how scientific knowledge has developed. We mimic the nature of scientific inquiry itself in how we teach it. But is this the most effective way to convey these ideas? And does it work with all students?
It is crucial that students understand the concepts, facts, and ideas that comprise our understanding of the natural world (NGSS Lead States, 2013). However, there is compelling evidence that when it comes to children, giving them a long list of facts, no matter how fascinating or compelling these facts and ideas may be, is not the best way to teach. Johnstone argues that the developing memory of children and early adolescents does not easily absorb a long sequence of scientific reasoning (1997). On the other hand, if you take a similar series of events conveyed as a narrative story, research shows it is more easily remembered (Weber 1993). Telling a story seems to be a way of helping children, and possibly all of us, incorporate a series of events into memory more readily. As Rowcliffe argues, “storytelling may help children to link cause and effect; hence illustrating a scientific concept in the form of a story improves pupils’ science learning” (p. 121). Classroom research supports this contention.

Researchers Diana Arya and Paul Maul found that a compelling narrative allowed students to better understand key science concepts (2012). They looked at the effectiveness of different methods of presenting ideas to middle school students in two northern California school districts. Using the examples of Marie Curie’s discovery of radium and Galileo’s discovery of the moons of Jupiter, the investigators compared how well students learned when presented with contrasting narratives. One was a straightforward historical account, while the other emphasized the discoveries from Curie’s and Galileo’s perspectives. Researchers compared how well students understood and retained the ideas that came from these discoveries. They found that students given the personal narratives performed better on tests and other measures of understanding, both immediately and long term. However, the researchers caution teachers not to go to extremes in telling stories. They found that the addition of exciting but unnecessary
material – what they called “seductive details” – hindered student learning. The inclusion of irrelevant or non-supporting facts not only tended to distort the historical record, but seemed to prevent students from retaining the information teachers wanted them to absorb (Klassen, 2014; Garner et al., 1992).

Other investigations comparing narrative accounts to standard expository explanations have come to the same conclusion. British elementary school students who were read two types of texts explaining the ideas behind biological evolution were found to have a greater understanding after hearing the story-based narrative versions (Browning and Hohenstein, 2015). The investigators suggested that imagination was critical to helping children understand. They pointed out that rote learning is often the main technique in science classrooms, but that narrative storytelling, with its emphasis on characters, their motivations and goals, and the events that challenge them, is easier for children to absorb and retain. Particularly when there is little prior knowledge of the subject, they found narrative texts to be superior to standard explanatory texts. They note that other research indicates the same may be true for adults.

The history of the development of scientific thought is full of the type of dramatic stories teachers can use in the classroom. Even an individual teacher’s personal stories of discovery and insight can be powerful illustrations of scientific insight. Although some elementary and secondary science teachers are taking steps to integrate storytelling into their classrooms, in general, the curriculum is still largely driven by content lectures and by inquiry-based investigations. While both have value, I argue that they are not sufficient. NASA researcher John Knox recalled that, as a university student in the 1980s and 1990s, almost all – 97 percent – of his classes relied on an instructor lecturing and students taking notes. He
argues that little has changed in the intervening decades. Although his prescription for change is aimed at the college level, I believe it applies to classrooms of all ages.

Knox argues in "Reform of the College Science Lecture through Storytelling" that university-level teachers should, at least in part, substitute stories for standard informational lectures. He says surveys show that as many as 90 percent of college courses still employ the instructor-centered oral lecture, as they have for the last thousand years of western higher education. Yet, he argues, the explanatory lecture is frequently criticized as an “inefficient and outdated form of communication” (p. 388), particularly in the age of the Internet and the ubiquity of online information. He says only a small minority of university educators use a narrative storytelling technique, and then often as a digression during a lecture or as a break from having to focus on the hard facts of the lecture. Knox does not suggest ending the instructor-centered college science classroom, but rather modifying it by systematically injecting storytelling as a way to teach the core material. The advantage, he argues, is clear.

A traditional lecture moves form one point to another in a linear “steamroller” fashion whereas stories by their very nature connect to listeners’ knowledge and ideas and “hang together” internally because of linkages between the characters in the story, the plot of the story, and the setting (p. 390).

The story would not replace the linear lecture, which often moves from generalization through supporting arguments, illustrations, and other proofs to a restatement and summary of the
main point. Instead, the narrative story allows students to connect these ideas in a more intuitive manner.

Knox outlines a range of narrative examples from which higher education storytellers could draw. But just as university-level teachers can adopt the pedagogic techniques more commonly used for younger students, teachers at all levels could use his examples. Among his suggestions of potential stories are the personal and professional lives of significant scientists and their discoveries. They offer a wealth of resources for potential storytellers. Although, as Knox suggests, historical narratives themselves can be used, they would likely be most effective if the central characters, and their trials and tribulations, are highlighted. Myths can be used, he says, to relate the overarching goals of the subject to the overarching belief systems of civilization. The story of Mary Shelley’s Frankenstein (Wolf, 1993) and other stories of the exploration of the unknown can be linked to scientific investigation. Creation stories can be compared to what we now know about the Big Bang. And, Knox notes, the detective story, centered on the efforts to solve a mystery, can be a rich theme in which scientific exploration and the nature of scientific research can be illuminated. Knox cites the search for the structure of DNA (Watson, 1968) and the cause of the end-Cretaceous extinction event (Alvarez, 1997) as examples. Many case studies can be used as effective mystery stories that students can be encouraged to solve.

A single story told in the classroom may be part of a larger, overarching, narrative theme. Knox calls this the narrative roadmap of a class. There can be, he suggests, a “natural rhythm of storytelling” (p. 391) that runs throughout the lectures of the course, beginning with recounting relevant myths to set the tone and context of the curriculum, followed by individual
stories of discovery to illustrate and personalize the content. Finally, he says, the teacher’s personal stories can help “establish the culture of science in the students’ minds” (p.391). In this way the instructor plans a story arc of an entire class, assuring that the stories that are told are authentically integrated into the overall narrative of the course.

As Knox points out, educators can draw on personal experience to generate a story in place of a lecture or traditional presentation. Telling stories about these experiences amplifies student interest and provides a personal narrative connection that would otherwise be lacking. I have used a variety of personal experiences to convey curricular ideas to my students: excavating a dinosaur fossil in Montana; being in the midst of a hurricane; and, seeing the impact of human activity in the Galapagos Islands.

When teaching about what fossils can tell students about the past, I describe a scenario I call “CSI: Ekalaka,” drawn from a week-long experience assisting with the excavation of a hadrosaur fossil in the badlands town of Ekalaka, Montana. I show them photos from the expedition, and from the museum where the fossil is now. I bring in fossils for them to touch. I describe what we found and what I experienced. Then I ask them questions: what can you tell from these bones? What does the rock surrounding them tell you? How did “Nancy” the *Edmontosaurus annectens* die? Why does she have a name? Is she really a she? How do we know what kind of dinosaur it is? Through this teacher-led interactive storytelling, they take apart this “crime scene,” asking their own questions, and perhaps arrive at a hypothesis for our evidence: that Nancy probably drowned in a flooded river delta, in an area that looked much like coastal eastern North Carolina. This then leads us to an exploration of paleogeography, of the Mesozoic inland waterway that covered the center of the continent, and how hurricanes
have wreaked havoc on lowland coastal areas for a hundred million years. Many stories, personal and otherwise, can lead to very fruitful explorations of the big ideas of science, particularly when integrated into the curriculum in advance.

Among the most important stories science teachers need to tell is that of the nature of science. These are stories that elucidate the process in which we search for understanding of the world around us. The nature of science is widely misunderstood by many and is often taught as a constrained “scientific method” that does a disservice to the richly imaginative and functionally diverse way in which we seek to understand the natural world. Related concepts that lend themselves to dramatic storytelling are accounts of how we came to understand ideas now taken for granted. These accounts can convey the excitement of discovery, expose the engaging and often quirky personalities of the protagonists, and dramatically illustrate the nature of scientific inquiry. Among the potential sources of these stories are historian Daniel Boorstin’s books *The Discoverers* (1985) and *The Seekers* (1998). Both offer a great range of examples, as does Simon Singh’s *The Big Bang* (2001), and Steven Gould’s *The Burgess Shale* (1990). The nature of science seems particularly important to emphasize given the common public disbelief of theories widely accepted by those who study them, such as evolution and human-caused climate change.

Stories taken from the professional lives of scientists can be compelling, particularly when they include the classic narrative elements of character, conflict, tension, and resolution. Biographies and autobiographies of notable personalities of scientific inquiry and discovery are rich sources. Oliver Sacks’ is an example; the story of his lifelong investigation into the mechanisms of the mind provides a wide variety of colorful anecdotes, as does his earlier
collection of case studies, *The Man Who Mistook His Wife for a Hat* (1998). But Sacks himself is a character who faced and overcame conflict, as he recounts in his autobiography, *On the Move* (2015). Although perhaps not appropriate for some classrooms, his accounts of coming to grips with his homosexuality in the 1940s and 1950s, of adventures riding his motorcycle across the back roads of North America, and of becoming a competitive bodybuilder meet all the qualifications for a dramatic narrative. Autobiographies and biographies of notable scientists, and accounts of discoveries and exploration are all fertile sources of stories that can enliven, illustrate, and inform a teacher’s classroom presentation.

Telling a compelling story is one way to use the narrative structure in a science classroom, but as discussed earlier, there are many methods, modes, and media available for effective storytelling. Students can also use written narratives, even novels and other fiction, to explore scientific ideas. Case studies can be effective, particularly if they take the form of a detective story that allows students to solve the key problem. Students themselves can tell stories, not only to inform others, but to authentically reflect on and demonstrate understanding of the material. The stories students tell can be oral and written, but can also be in the form of animations, videos, and other digital media, cartoons and graphic novels, other visual arts and even as movement and dance. As Gardner urged, it is valuable not only to approach students through the range of multiple intelligences, but to allow them to express their understanding through the same range. I examine several examples below.

*The case study* is already used in a variety of teaching situations, from elementary school to graduate programs. Often these detective stories are non-fiction portrayals of actual events and situations but they can be fictional as well. What is important is that they provide a
pedagogically relevant, provocative mystery for students to solve and, if possible, an ethical
dilemma and conflict to engage them. Clyde Herreid, of the National Center for Case Study
Teaching in Science, lists a range of characteristics that make a compelling case study (1997).
He says a good case tells a story, has an interesting plot, and a narrative arc, but is also
ambiguous and open ended. An effective case study also focuses on an interesting and
controversial issue and is relevant to the students’ lives and interests. A good case creates
empathy with the characters’ plight and dilemma. Students must care about them and about
the outcome of the case. And it must invite an urgent, critical decision to be made. Herreid says
“without a dilemma in the case, a student can sit back and tsk tsk the way that a case unfolded.
When they are forced to take a position, they are thrust into the action of the case” (1997, p.
164). The story, he says, must be real enough that the reader or participant believes it is worth
solving and to care about the solution.

Teachers may draw on their own experience to introduce a personal perspective to a
case study. For example, I have used my experience working with residents of the Galapagos
Islands’ largest town, Puerto Ayora, to introduce a case study of the conflict between the needs
of a growing human population and the necessity of preserving a unique natural biological and
evolutionary heritage. Involving a personal perspective, I believe, powerfully engages the
interest of my students. Herreid and colleague Nancy Schiller provide an example of how to use
the Galapagos as a lesson in both evolution and land use conflict in their article, “The
Galapagos: A Natural Laboratory for the Study of Evolution” (Schiller, 2000).

A related example of case study is the “living case,” an outside speaker or guest who
brings a personal case story to the classroom. In order for this to be an effective “case” rather
than simply a guest speaker, the teacher must invest a significant amount of time in planning for the visit. The individual must be an engaging storyteller, the case portrayed must be a compelling example that reinforces the curriculum, and students must be prepared for the visit with appropriate background. But when managed well, a living case may bring a unique perspective to the classroom, and have a significant, memorable impact on students (Fawcett and Fawcett, 2011). Professional scientists, particularly those whose field of study is accessible and relevant to the students’ lives, may be particularly valuable as examples of the process of inquiry and investigation. Although developing a living case takes time and effort, if the experience was successful, the guest can be invited back to future classes using the same lesson template.

Although not usually considered part of the science curriculum, novels, other fictional literature, and movies can be used as a form of case study. The dramatic tension, characters, and story arc are readily apparent and can stimulate student interest. Similarly, fables and myths can be used in the science classroom. A fable appropriate to the elementary or middle school science classroom called *Fish Tank* is a cautionary story about with climate change (Bischke, 2012). It follows the story of a group of sea creatures living in a fish tank whose owner goes on a trip, leaving them in the care of a negligent janitor. With the temperature rising and a crack developing in the tank, its occupants must figure out how to work together to solve their crisis. The book could be a reading assignment, or the teacher could read it aloud to younger students. *Fish Tank* is an effective allegory that raises questions that do not have simple

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4 Examples of appropriate science-related fiction (depending on the age level of the classroom) are Michael Crichton’s novels, including *Jurassic Park*, the related book, *The Science of Jurassic Park* (Lindley, 1997) and *State of Fear*, and films *The Martian, Jurassic Park*, and *Gattaca*.  

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answers and thus are open to classroom discussion and interpretation. (A series of guiding
questions is available.) It is crucial for the teacher to make an informed choice about the
underlying science in such works so that it supports the curriculum; otherwise the study of the
fiction can be distracting and may even create misconceptions. This is particularly important in
choosing fictional films to show in the classroom. As in the “living case” example, proper
preparation of students is crucial, as is an effective method for them to process, reflect on, and
reinforce the subject material. But with these caveats in mind, the use of fictional storytelling
can be effective in stimulating learning (Herreid, 2002, 2005; Tobias, 2000).

*Student digital storytelling* is emerging as a new pedagogical technique that allows
students to process and reflect on their learning and engages them with appealing technology
tools. Digital storytelling makes use of a wide range of media including video, stop-motion
animation, sound recording and design, and photos, often in combination. It is effective
because it brings together student-centered learning strategies including project-based
learning, cooperative engagement, reflection on learning, and integration of technology (Sadik,
2008). The product can be as simple as a recorded story or as complex as a multi-media video
presentation, but regardless, because it involves telling and retelling of stories, encourages
student thinking at a deeper level (Wang and Zhan, 2010). Composing a digital story proceeds
along the same lines as any type of narrative composition; the author considers the structure of
the story, the perspective, the character. But included in the available tools are photos, other
images, animations, video, and voice narration. Before final production the student will create
multiple drafts of both written material and storyboards (the sequence of simple images and
drawings visualizing the video sequence). These drafts are most effectively produced digitally so
both teachers and collaborators have access and revisions can easily be made. Video and audio editing software is available both online as standalone programs.

Much of the emphasis in digital storytelling in education lies in allowing students to express their individuality and to tell their personal stories. This focus allows for the creation of a strong narrative and individual voice, which may not be as appropriate in the science classroom as in that of a language arts or social studies teacher. But digital stories can be effectively used to explain scientific concepts, particularly when framed as an individual exploration. Science teacher Alfred Olivas (2013) explored the idea of a digital laboratory report as an alternative to the conventional written report. Students found documentation of experimental techniques and results engaging and Olivas found the students’ process of organizing and creating the final short documentary productions an effective way to evaluate their progress. Olivas encouraged students to insert short explanatory video segments, which he found allowed them to express personality as well as understanding. While this example of storytelling does not directly match the standard story narrative, encouraging students to visualize the production as a “story” rather than a collection of factual material also encourages them to envision and understand overarching themes and concepts.

*Roleplaying as storytelling* focuses on a character rather than a narrative. Science teachers have enlivened lectures on evolution by portraying Charles Darwin, or basic physics by taking the role of Newton. As has been noted, a narrative with a memorable protagonist can be compelling. At my school, on Halloween, teachers have an opportunity to come to school in costume and to engage students in a playful interaction that builds on the energy most students bring to this celebration. They day before, I informed my students that I will be absent
on Halloween, and that they could expect, as a substitute teacher, my “long lost cousin from
Germany.” On Halloween, I arrived in costume, with a white wig, white mustache, lab
coat, and spoke with a German accent, portraying a character that, although based loosely on
Albert Einstein, also includes elements of the “mad scientist.” I stayed in character throughout
the class. My experience has been that this character is most effective when humorously
exaggerated, and when the detail comes not from direct explanation but from the questions
students ask. The demonstration and lesson centered on a Halloween theme: a “self-carving
jack-o'-lantern.” I prepared the demonstration pumpkin by carefully carving a face and
replacing the pieces so as to make it difficult to notice without close observation. Inside, I
placed a metal dish containing a small amount of calcium carbide, which reacts with water,
forming acetylene. (This demonstration is always done outside at a safe distance, with all
observers wearing safety goggles!) I then, with dramatic effect, asked a volunteer to get some
water. I lifted off the top of the jack-o'-lantern, poured in a small amount of water, and quickly
set the top back in place. Suddenly there was a loud explosion, an eruption of yellow flames
from the front of the pumpkin, and the face of the jack-o'-lantern appeared amid the smoke
and flame. The students screamed with surprise and delight. The teaching opportunity arose
from the questions students posed, starting with “What happened?” I answered with more
questions: What did you see? Is there evidence of a chemical reaction? Can water explode?
What else could have happened? What do you think that means? Students first offered
observations: they saw “steam” rising from the pumpkin after I poured the water in; I had
reached behind the pumpkin right before the explosion (I had inserted a long butane lighter in
the back of the pumpkin without telling them); I must have carved the pieces of the face earlier;
and those pieces of the “face” smelled strongly of smoke. I answered few questions until they had generated their own ideas and hypotheses about what they saw. Eventually I allowed them to convince Dr. Al to do it again while they watched, and they discovered that the water reacted with a chemical that produced “smoke” that was highly flammable.

While this dramatic introduction to exothermic reactions could be done without playing a role, it is my experience that the presence of “Dr. Al” provides the context that makes the demonstration far more memorable. I have shown students the self-carving jack-o’-lantern for many years, and it is the character former students remember. They ask if “Dr. Al” still visits at Halloween, and whether his accent is as difficult to understand as they remember. For current students, seeing the character early in the class prompts their eagerness for what they have heard is coming. The role is critical to creating the aura of mystery that prompts their questioning and curiosity.

It is not only the teacher who can portray a character role, and tell a story through drama. Students can be engaged in performing as a character or creating a scene to explain a scientific concept or discovery or to portray a particular scientist. This classic form of storytelling allows students to use another form of multiple intelligence expression. Englund and Stanley (2014) have effectively used this technique in a fifth grade classroom not only to teach content (reading, writing, and editing) but to encourage cooperation and collaboration, and reflective self-improvement. In this case, students learned, revised, rewrote, and performed African folk tales. Their performances included expressive movement in addition to storytelling. Englund said even hesitant and uncertain students were energized by this assignment: “I overheard conversations about themes, settings, characters, even plots.
Individually, students were comparing and contrasting stories! They loved the content of the stories and the independent nature of the activity (p. 26). This type of project-based assignment encourages independence and self-teaching. Englund reported that as she “became less front and center, they moved into that position. They owned their learning” (p. 28). She noted that as a result of this active engagement in telling a story, student writing ability significantly improved.

*Movement and dance based storytelling* is not likely on many science teachers’ agenda. Yet, as with acting, dance engages a student at a kinesthetic level that is shown to facilitate learning and neural development (Grafton, 2009; Stevens-Smith, 2004). Inspired by the American Association for the Advancement of Science “Dance your PhD” competition⁵, a colleague and I have effectively used interpretive dance to teach scientific concepts to middle school students. Annie Dwyer, the Carolina Friends School dance instructor, and I began this semester long elective class by teaching students the “vocabulary” of basic dance movement – allowing them to learn how to move their arms, legs, and bodies, and how to themselves move through space in various directions. We then viewed time lapse video of plants growing and flowers blooming, and encouraged the students to emulate those motions. As they became comfortable moving and interpreting motions, we gave them more complex ideas to interpret, such as groundwater movement and the transmission of nerve impulses. At this point students chose and researched science topics, including the movement of the planets, insect metamorphosis, subatomic particle interactions, tsunamis, and plate tectonics. We then assigned students to small groups of two to five students in order to develop some of the ideas.

⁵http://www.sciencemag.org/news/2016/06/science-launches-2016-dance-your-phd-contest
They spent the several weeks transforming the ideas they had researched into interpretive dance. Dances were set to music during the process, which was developed by each group of students independently. We concluded the class with an experiment. When one student asked how a flock of birds can change direction seemingly in an instant, I discovered research (Cavagna et al., 2010) that revealed the answer: each bird matches its movement to its six or seven closest neighbors in the flock. The result is a wave of motion spreading through the flock, resulting in the near instantaneous movement of hundreds of birds. I wondered if we could simulate that motion with thirteen middle school students. I instructed them to move together around the performance space, matching their movement to that of their nearest two neighbors. As they became comfortable moving together, I played the role of a hawk, approaching suddenly, while reminding them to only match their movement to their nearest neighbor. What we discovered is that the simple movement matching behavior was effective in abruptly changing the direction our “flock” moved.

As with the complex task of editing a digital story or developing a storytelling performance, it is important for the teacher to actively supervise and assist in the editing and development process, particularly to help students keep their focus on the scientific idea. Although we allowed some leeway for abstract expression, the underlying concept and overall movement had to portray the science ideas. We evaluated the students’ understanding by observing how they developed their movements, by interviewing them, and by having each student explain their ideas to the others. While this elective class combined the knowledge of a dance instructor and a science teacher, elements of this exercise could easily be modified for use in a science classroom.
At a time when accepted scientific ideas face challenge from cultural or political
opponents, and the objectivity and trustworthiness of science professionals and the research
establishment is questioned, it is relevant to help students understand the nature of science
and their roles in its study. On the first day of science class I ask my seventh grade students to
close their eyes and take a moment to imagine what a scientist looks like. I tell them to create a
visual image in their minds. Now, let’s describe this person, I say, and ask them to call out
characteristics, which I write on the whiteboard: “He’s wearing a white coat.” “He has a funny
look on his face, a little crazy.” “Oh, and he has weird hair!” “And glasses!” “And test tubes –
he’s holding some smoking chemicals that are about to explode!” I project an image of an
archetypal mad scientist (just search for images of “mad scientist” to see the type) and they
shout “Yeah! That’s him!” Then I show them a photo of the older, white haired Albert Einstein.
They recognize the image and shout, Yes, him too! We then talk about these stereotypes of
what a scientist looks like, not the least of which is the consistent use by most students of the
masculine pronoun. Now in truth, not all fall for my trick. Teaching in a university town, I know
that some have parents who are professional scientists. They and others realize that the image
we’ve conjured is not an accurate representation. But all are familiar with the popular
stereotype. My point to them is that science is not necessarily the work of the deranged or the
brilliant but of real people. My final image is a picture of a former student looking inquisitively
at a praying mantis perched on her finger. I suggest to them that this is what a scientist looks
like.
Conclusion

Symbolic language is unique to Homo sapiens – it has allowed us to survive and thrive as a species and has enabled our complex and diverse cultures to flourish. Indeed, the ability to think symbolically may be the small genetic change that made us the sentient beings we are. Language allows us to express ideas, explore our imagination, and to create an internal image of the world that allows us to see beyond ourselves. Science is a way to understand that world, and is at its essence a manifestation of that same symbolic element of our consciousness. Yet many see science as a world they do not understand, that is not open to them, and is a world and do not entirely trust. In an academic context, science is often seen as being at odds with the humanities. I have argued that that far from being mutually exclusive, the rational, reasonable world of science is closely aligned with what makes us human. Edward O. Wilson calls this idea consilience, a “jumping together” of knowledge that creates an integrated vision of how we perceive the world. In *Consilience: The Unity of Knowledge*, Wilson says,

Every college student should be able to answer the following question: What is the relation between science and the humanities, and how is it important for human welfare? Every public intellectual and political leader should be able to answer that question as well (p. 13).

Without bridging this gap, he says, we cannot solve the major problems that face humanity, and we cannot have a balanced view of the world. Telling stories to teach science can help bridge that gap.
Storytelling is among the oldest and most effective ways of sharing knowledge. It probably has deep genetic roots and certainly is biologically compelling. I have argued that science education greatly benefits from the use of narratives to convey and reinforce learning, and have laid out some of the ways in which science teachers can use them. It is by no means an exhaustive or complete list. However, it is my hope that science teachers, emboldened and encouraged to explore these pedagogical techniques, will find many more ways to tell stories and teach science.
Bibliography


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