THESIS

WHAT'S THE STORY? THE EFFECTS OF NARRATIVES IN SCIENCE CLASSROOMS

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ABSTRACT

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While effective science communication is crucial, it also presents multiple obstacles for natural science researchers and specialized communicators. This includes a language divide between scientists and the general public, making science less approachable to novices. The use of narratives within science represents a powerful strategy for overcoming these issues. We examined the reported effects of narratives as a communication strategy and reviewed the varying definitions of narratives in the literature. We propose a set of essential elements that differentiate narrative communication from other forms, all of which are useful for researchers seeking to understand the impacts of stories. These elements include *events*, *characters*, *causality/agency*, and *conflict/resolution*.

We also studied the effects of training graduate teaching assistants (GTAs) using narrative communication. We examined i) what narrative elements GTAs incorporated into their own lessons, ii) why they chose to include stories in their classes, and iii) how training affected content knowledge and self-perceptions for GTAs and their undergraduate students. We found that GTAs who were trained using stories were more likely to integrate the narrative elements into their lessons. Additionally, when employing narratives, GTAs focused on the process of science rather than the results. However, the GTAs did not demonstrate or perceive any concrete knowledge gains. Finally, we argue that narratives can and should be incorporated into more introductory courses across multiple disciplines.

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CHAPTER 1: NARRATIVE ELEMENTS IN SCIENCE COMMUNICATION

Introduction

The value of ecological and other natural scientific studies is diminished when researchers are unable to communicate their findings outside of their science community. Research has shown that science communication is both crucial and, unfortunately, often poorly executed (Treise & Weigold, 2002). The manner in which science is commonly explained presents only the results, rather than the entire process (Lemke, 1990). This can lead to students perceiving science as a daunting and unachievable goal, creating an immediate barrier between scientists and members of the general public who lack formal science training (Lemke, 1990). Adding to that divide is the fact that lessons on and descriptions of science often begin in the middle of the conversation (Tallis, 1995). This conversation is created when scientists build off of and respond to previous research, but if the audience is not familiar with the first part of the discussion (the foundational work), they face an immediate obstacle.

Science communicators commonly act as the bridge between researchers who produce knowledge and the public who consume it (Weingart & Guenther, 2016), but natural scientists who rely on popular media to convey their findings to the general public are often disappointed by how their results are communicated (Hartz & Chappell, 1997). Natural science researchers who try to communicate directly with the public sometimes face a language divide due to the divergence of scientific language from that generally used by non-scientists (Treise & Weigold, 2002).

Several solutions have been proposed for spanning the divide between scientists and the public. Researchers are now challenging the earlier-proposed *deficit model*, which posited that the public simply lacked the facts available to scientists and the solution was transmission of information (Groffman et al., 2010). The limited view of this model does not take into account an audience's identity and previous experiences (Groffman et al., 2010). Additionally, the deficit model focuses on what information is being communicated without considering the manner in which it is conveyed to the audience.

One proposal for how to effectively communicate science is grounded in the concept of argument framing. Framing, as described by Goffman (1974), allows individuals to situate scientific concepts and issues within an audience's existing world view. Proponents of framing argue that it allows scientists to reach a broader audience by shifting the discussion of a scientific topic to a background that is more relevant to the public (Nisbet & Scheufele, 2009). This tactic supports the idea that people are more able to retain and understand information when it connects directly to their personal lives (Brossard & Lewenstein, 2010).

Another strategy for increasing the efficacy of science communication is the use of narrative, rather than expository, communication. Expository writing, which is associated with academic science writing, is informative but often lacks explicit opinions or storylines (Balgopal & Wallace, 2013; Klassen, 2009). Narratives include those missing opinions and storylines, but also incorporate several other key elements that will be discussed later in this paper. Historically, the greatest difference between the narrative and expository genres was their intent. Expository texts were meant to communicate information, while the goal of narratives was to entertain the audience (Weaver & Kintsch, 1991). Accompanying this previous difference was the fact that the use of narratives as a communication strategy was discouraged by many natural scientists (Gould, 1991). Narratives were viewed as a way to simplify or adulterate the actual science (Gould, 1991). It is now clear, though, that narratives can be informative and scientifically accurate, while also incorporating elements of non-scientific communication. In fact natural scientists often engage in storytelling, even if they do not label it as such. Many seminal books and articles written about natural science are presented in the form of a story. The typical research paper tells a narrative of how the scientific study was conducted, with the scientists or research subjects acting as the main characters. Even the conventional structure of a journal article (introduction, methods, results, and discussion) mirrors the broad structure of a story (beginning, middle, and end) (Olson, 2015). It behooves scientists, who want to intentionally and actively improve their communication through the use of storytelling, to know the elements of narratives and to then understand how the audience may respond (e.g., how learners make meaning of content).

Effects of narratives

Sean Prentiss, an author and professor of narrative non-fiction, describes the effects of narratives by stating that "if you teach me a theory, I will learn it. But if you allow me to see and live within that theory (even if only in story), I will feel it" (S. Prentiss, personal communication, 12/19/16). Prentiss speaks to the potential benefits of using narratives to communicate science, allowing an audience to engage with the material. Rather than simply receiving the scientific information, the audience can situate the material using their past experiences and knowledge. Narratives can allow audience members to cross the initial barrier that may exist for the general public making sense of scientific content (Kreuter et al., 2007). Because stories are a familiar format, a narrative can act to increase comfort levels with unfamiliar material (Prins, Avraamidou, & Goedhart, 2017). As science becomes more familiar, it also becomes more inclusive, attracting students and audiences who might initially feel that science is inaccessible (Avraamidou & Osborne, 2009). Narratives therefore, can be appealing to more diverse audiences, including those from underrepresented groups in science disciplines, such as women, African-Americans, Latinos, Africans, and indigenous peoples (Mutonyi, 2016; Norris, Guilbert, Smith, Hakimelahi, & Phillips, 2005).

Through their inherent characteristics, narratives can also reinforce improved communication strategies (Schank & Berman, 2002). Writing stories often requires communicators to provide context for their explanations and to explicitly address potential misconceptions that readers may have (Downs, 2014). Narratives also allow science to be communicated at a human scale (Dahlstrom, 2014). Stories can present content that is at small or large scales, such as molecular or astronomical information, in repackaged ways that an audience can more easily relate to (Dahlstrom, 2014). This effect on communication is seen repeatedly in Stephen Hawking's A Brief History of Time (1988). Hawking describes the effects of black holes, a concept that exists at a large scale that makes comprehension difficult, by telling stories about theoretical human interactions with them.

> *The existence of radiation from black holes seems to imply that gravitational collapse is not as final and irreversible as we once thought. If an astronaut falls into a black hole, its mass will increase, but eventually the energy equivalent of that extra mass will be returned to the universe in the form of radiation. Thus, in a sense, the astronaut will be "recycled". It would be a poor sort of immortality, however, because any personal concept of time for the astronaut would almost certainly come to an end as he was torn apart inside the black hole! Even the type of particles that were eventually emitted by the black hole would in general be different from those that made up the astronaut: the only feature of the astronaut that would survive would be his mass or energy* (p. 143).

By using a human to explain these astronomical effects, Hawking reframes the information as a story that can be clearly imagined and understood by the reader.

Engaging narratives can also have positive effects on learning outcomes. The use of stories has been shown to increase memorization, learning, and information processing for students (Kreuter et al., 2007; Schank & Berman, 2002). Integrating narratives in science classrooms allows students to identify the relevant information, leading to faster reading, better comprehension, and longer retention (Negrete, 2003; Prins et al., 2017; van Haneghan et al., 1992; Zabrucky & Ratner, 1992). The increased retention of content can be explained by the fact that students are able to visualize the concepts and events when they are presented in stories (Prins et al., 2017).

Despite the positive impacts of narrative science instruction, researchers have also identified several potential weaknesses. Stories may not be ideal if the primary goal is to prompt verbatim recall (Downs, 2014). Additionally, stories may readily lend themselves to presenting biased results as they are likely presenting only one perspective (Downs, 2014). Finally, as narratives often weave together facts and fictional embellishments, audiences may find it difficult to tell the difference between the two (Prins et al., 2017).

How audiences respond to narrative science communication is highly context dependent. Glaser, Garsoffky, & Schwan (2009) argued that narratives are more likely to be beneficial when the educational content is built directly into the story. When the science is tangentially related to the events in the narrative, the science and the story can compete with one another, blocking either from fully reaching the audience (Glaser et al., 2009; Negrete, 2003). For example, a documentary discussing the work of Charles Darwin is likely to contain a large amount of embedded science content, whereas a film on his personal life may only contain science tangentially related to the central narrative. To better understand the effects of storytelling and narrative communication in science classrooms, it is necessary to operationalize the definitions of narratives and the elements used to distinguish this form of instructional delivery.

Narrative definitions

Due to the diverse definitions of narrative communication, comparing studies of the effects of narrative communication can be challenging, resulting in ambiguous findings across the research literature (Hinyard & Kreuter, 2007). Although we may intuitively recognize a narrative, it can be difficult to define the specific characteristics that differentiate it from other forms of communication. This is because there are no innate limits to, or one singular formula for, stories (Bruner, 1986). Traditionally, the most basic characteristic of a narrative is that there is an unforeseen turn of events, what Aristotle described as the *peripeteia* (Bruner, 2002). Moreover, there are usually characters, narrators, and readers (Bruner, 2002).

While these broad descriptions are useful when considering narratives loosely, they lack the specificity and replicability to be used in research. To rigorously examine the effects of narratives in science communication, we need an instrument that will allow us to identify narrative texts. Some studies on narrative communication fail to describe what defines a story (e.g., Negrete 2003), but most describe them using a series of elements. The elements from the varying definitions can be broken down into two categories (Table 1). These groups are adapted from Lawson et al. (2000) who categorized the types of scientific concepts presented in undergraduate classrooms. While Lawson's categories (theoretical, hypothetical, and descriptive) do not directly translate to the elements of narratives, the latter two inform the development of a useful framework for science narratives used in instructional delivery.

The *hypothetical* narrative element can putatively be observed, but due to limitations, this is challenging. Hypothetical elements are often components that may be visible only to the author or audience of the narrative but are impossible to observe directly in the narrative artifact. For example, one hypothetical element is *purpose*. The purpose of a narrative, unless explicitly stated, is likely only known to the author of the story. *Descriptive* narrative elements, on the other hand, are directly observable by examining solely the narrative text. A researcher can empirically perceive these components, making them more useful when considering research instruments. For example, the descriptive element *conflict* is an obstacle that is placed between a character and their goals; alternatively, it can be a question that is unanswered at the beginning of the story. In either case, conflict is visible in the narrative artifact.

Lawson et al. (2000) described *theoretical* concepts, which, in the context of narrative elements, are those that researchers use to situate their own work but are not directly observable. Theoretical elements are not useful for developing research instruments because they are not necessarily visible and as such, are unlikely to be replicable (i.e., decreasing high inter-rater reliability of findings). Although theoretical elements have utility in broadly defining stories, because the literature on scientific narratives is largely devoid of theoretical elements, this review will focus on the hypothetical and descriptive elements.

Hypothetical elements

Most stories have a *narrator* (Diasamidze, 2014; Kubli, 2001). The narrator tells the story to the audience, often crafting other elements of the narrative (Norris et al., 2005). The narrator may be an actual character in the story or may have an implied presence (Avraamidou & Osborne, 2009; Chatman, 1978; Downs, 2014; Kubli, 2001; Toolan, 2001). If the narrator is not an active agent in the story, they may be difficult for the researcher to describe. Additionally, a general sense of a narrator is likely present in all forms of communication and is therefore not unique to narratives. Although narrators may be unobservable, one visible example of a clear narrator is found in Lynn Margulis' Symbiotic Planet: A New View of Evolution (1998). In the following passage, Margulis describes her experiences conducting field work:

> *In search of the ecological setting of the earliest cells on Earth, every few years* ***my students*** *and* ***I make*** *a pilgrimage to San Quintín Bay, in Baja California Norte, Mexico.* ***We seek*** *the shifting shores of Laguna Figueroa, a lagooned complex festooned with salt flats. Here* ***we*** *find laminated, brightly striped sediments underlain by gelatinous mud. These colorful seaside expanses, called "microbial mats,"* ***enchant me****- a living landscape just where the sea meets and rolls back and forth over the land. Luckily for* ***our studies****, the scene is inhospitable to the vast majority of large life-forms, humans included.* ***I put*** *my hands in the mud of fragrant microbial tissues and whiff the exchanging gases… Standing at the microbial mat****, I feel privileged****.* ***I delight in escape, thrilled*** *to abandon the urban sprawl of human hyperactivity and* ***exhilarated*** *with the freedom to contemplate life's most remote origins* (p. 69-70).

The presence of a narrator is at the forefront in this excerpt and is highlighted by the bolded text. By describing the experiences from the first-person point of view, she is filling the story with her own personality, emotions, and beliefs. The reader learns that she is enchanted, delighted, thrilled, and exhilarated. This is not the same information that they would be given if the narrator was someone else or was absent entirely. While this particular narrator is visible to the audience, and any potential researcher, this not always the case.

A second proposed element of narratives, in conjunction with the narrator, is that there is a *reader or audience*. The reader interprets the text and responds to it, while the interpretation is shaped by the audience's expectations of stories (Avraamidou & Osborne, 2009; Chatman, 1978; Norris et al., 2005). In this way, the narrator and the audience are co-creating meaning from the text. Just like the element of the narrator, the audience is neither unique to narrative communication nor is it likely observable. Norris et al. (2005) extended the concept of audience by adding a third element, *narrative appetite*. They claimed that the audience needs to be engaged and motivated to keep listening/ reading in order to discover what will happen. Although this is arguably a useful element for a story to have, not all narratives require narrative appetite; i.e., a story is still a story even if the audience is not interested in it's content (Avraamidou & Osborne, 2009).

Stories should also have a *purpose*, which depending on the definition, can be to help the audience understand the human or natural world (Norris et al. 2005, Avraamidou and Osborne 2009) or may be as broad as conveying information (Schank & Berman, 2002), knowledge, feelings, values, or beliefs (Phelan, 1996). While all narratives likely have a purpose, this is not unique to narrative communication; all communication has some inherent purpose. Furthermore, the purpose of a narrative may not be explicit or observable to a researcher. While the purpose of many pieces of scientific communication may be to educate the audience on a certain subject, the purpose is defined by the intent of the author, which cannot be known for certain unless the author states this explicitly as a preface or afterword.

Some narratives also should contain a *theme*. Thorndyke (1977) argued that theme was a requisite component of narratives. Theme is described as the "general focus" of the story or the primary goal of the main character, and could be either implicit or explicit (Thorndyke, 1977). The goal is often justified within the story through a series of events that explain the character's motivations (Thorndyke, 1977). This is another example of an element that is often not observable in a narrative artifact.

The final hypothetical element is an *identifiable structure*. Although in name, one would assume that this should be observable, many of the descriptions of the structure are vague and nebulous, making the structure implied. Some studies only describe the structure as needing to be clear or identifiable, without clarifying what a narrative structure should be (Kreuter et al., 2007; Schank & Berman, 2002). Toolan (2001) posited that stories should "go somewhere." Some definitions describe the structure of a narrative as containing a beginning, middle, and end (Avraamidou & Osborne, 2009; Hinyard & Kreuter, 2007). Others explain that narrative structures may begin with imbalances and end in some sort of resolution (Norris et al., 2005;

Thorndyke, 1977). Van Peer and Chatman (2001) elaborated by claiming that a story should flow through events in a particular structure and order: imbalances, protagonists addressing the imbalances, complications from attempts, crises, followed by success or failure. Egan (1986) described a simplified structure where a story begins by creating expectations, introduces complications, and eventually leads to satisfaction. While some stories contain an easily mapped arc hitting the structural components described by many of these authors, for most narratives, and other forms of texts, this is unobservable.

Descriptive elements

Descriptive elements can be directly observed in a narrative artifact. To illustrate the eight descriptive elements, this review will use examples from the science literature, specifically writing focused on ecology and the environment. In al cases, the elements will be highlighted with bolded text. One of the most common descriptive elements is the inclusion of *events*. In a narrative, the events are connected and work together to create larger meaning (Avraamidou & Osborne, 2009; Chatman, 1978; Kreuter et al., 2007; Norris et al., 2005; Taylor, 1982; Thorndyke, 1977; Toolan, 2001). The events are related to one another temporally, although there are differing opinions as to whether they need to be presented sequentially (Norris et al., 2005; Taylor, 1982). Thorndyke (1977) described the narrative events as episodes, which are made up of actions, that collectively form the plot. Some authors also argue that the events should be unique and unlikely to occur again (Moffett, 1968; Norris et al., 2005).

Within science and environmental writing, events are visible in Henry David Thoreau's short piece "Death of a Pine" (Thoreau, 1982 as cited in Coulson, Whitfield, & Preseton, 2003). This essay describes Thoreau's observations as a tree is felled.

> *This afternoon, being on Fair Haven Hill, I heard* ***the sound of a saw****, and soon after from the cliff* ***saw two men sawing*** *down a noble pine beneath, about forty rods off. I*

resolved to ***watch it till it fell****, the last of a dozen or more which were left* ***when the forest was cut*** *and for fifteen years have waved in solitary majesty over the sproutland. I saw them like beavers or insects gnawing at the trunk of this noble tree, the diminutive manikins with their cross-cut saw which could scarcely span it. It towered up a hundred feet as* ***I afterward found by measurement****, one of the tallest probably in the township and straight as an arrow, but slanting a little toward the hillside, its top seen against the frozen river and the hills of Conantum.* ***I watched closely*** *to see when it begins to move. Now* ***the sawyers stop****, and with an axe open it a little on the side toward which it leans, that it may break the faster. And now* ***their saw goes again****. Now surely it is going; it is inclined one quarter of the quadrant, and, breathless, I expect its crashing fall. But no, I was mistaken;* ***it has not moved an inch****; it stands at the same angle as at first. It is fifteen minutes yet to* ***its fall****. Still its branches wave in the wind, as if it were destined to stand for a century, and the wind soughs through its needles as of yore; it is still a forest tree, the most majestic tree that waves over Musketaquid. The silvery sheen of the sunlight is reflected from its needles; it still affords an inaccessible crotch for the squirrel's nest; not a lichen has forsaken its mast-like stem, its raking mast - the hill is the hulk. Now,* ***now's the moment****! The manikins at its base are fleeing from their crime. They have dropped the guilty saw and axe. How slowly and majestically* ***it starts****! As if it were only swayed by the summer breeze, and would return without a sigh to its location in the air. And now it fans the hillside with its fall, and* ***it lies down*** *to its bed in the valley, from which it is never to rise, as softly as a feather, folding its green mantle about it like a warrior, as if, tired of standing, it embraced the earth with silent joy, returning its elements to the dust again. But hark! there you only saw, but did not hear. There now comes up a deafening crash to these rocks advertising you that even trees do not die without a groan. It rushes to embrace the earth, and mingle its elements with the dust. And now all is still once more and forever, both to eye and ear.*

I went down *and measured it. It was about four feet in diameter where it was sawed, about one hundred feet long. Before I had reached it the axemen had already divested it of its branches. Its gracefully spreading top was a perfect wreck on the hillside as if it had been made of glass and the tender cones of one year' s growth upon its summit appealed in vain and too late to the mercy of the chopper. Already he has measured it with his axe, and marked off the millions it will make. And the space it occupied in the upper air is vacant for the next two centuries. It is lumber. He has laid waste the air.* ***When the fish hawk in the spring revisits the banks*** *of the Musketaquid, he will circle in vain to find his accustomed perch, and the hen-hawk will mourn for the pines lofty enough to protect her brood. A plant which it has taken two centuries to perfect, rising by slow stages into the heavens, has this afternoon ceased to exist. Its sapling top had expanded to this January thaw as the forerunner of summers to come. Why does not the village bell sound a knell? I hear no knell tolled. I see no procession of mourners in the streets, of the woodland aisles.* ***The squirrel has leaped to another tree****; the hawk has circled further off, and has now settled upon a new eyrie, but* ***the woodman is preparing to lay his axe to that also*** (p. 41-42).

In this detailed description, Thoreau covers a long series of events, including his initial view of men sawing, his anticipation of the tree's fall, and the moment when the pine actually falls down. He then predicts the events that will occur when the wildlife returns and discovers the tree is gone. By combining multiple events, along with the woodman preparing to cut down the next tree, Thoreau creates greater meaning about lasting effects of the tree's death as part of a cycle of logging.

Several authors argue that narratives should focus on another descriptive element, *time,* by integrating past events (Avraamidou & Osborne, 2009; Norris et al., 2005), while others care more that the events occur in a described, discrete period of time (Dahlstrom, 2014; Downs, 2014). A retelling of experiences is another strategy used by authors that indicates past time (Schank & Berman, 2002; Toolan, 2001), and while these experiences can be either true or fictional, they must have occurred in the past (Schank & Berman, 2002).

An example of the time element can be found in Rachel Carson's seminal book about environmental science and advocacy, Silent Spring (1962). In the following brief passage, Carson describes the creation of DDT, the insecticide that was the focus of her work:

> *DDT (short for dichloro-diphenyl-trichloroethane) was first synthesized by a German chemist in **1874**, but its properties as an insecticide were not discovered until **1939**. Almost immediately DDT was hailed as a means of stamping out insect-borne disease and winning the farmers' war against crop destroyers overnight. The discoverer, Paul Müller of Switzerland, **won the Nobel Prize*** (p. 20).

In this excerpt, Carson places the events surrounding the invention of DDT in a clear, discrete period of time, all of which takes place in the past. She provides a set of dates but also uses the jump in years (1874-1939) to demonstrate that the chemical had little importance (at least to her story) until it was considered an insecticide. The sequence of events implies that time must be passing – Müller could not have been awarded the Nobel Prize before he discovered the insecticidal qualities of DDT.

C*onflict* and *resolution* are also important narrative elements. The narrative provides some sort of conflict or unanswered questions early in the story (Downs, 2014; Hinyard & Kreuter, 2007). Through actions put into motion by the agents and characters, the conflict is eventually resolved (Downs, 2014; Hinyard & Kreuter, 2007; Thorndyke, 1977). On the surface these elements may appear simple, but without conflict and resolution, there would be very little action taking place over the course of the narrative. Olson (2015) argued that conflict and resolution are intrinsic components of a story's structure. He suggested that a strong narrative follows the ABT (And, But, Therefore) model, where *but* represents a conflict and *therefore* is the eventual resolution.

Examples of both conflict and resolution are found in Garrett Hardin's seminal paper *The Tragedy of the Commons* (1968). The issue that Hardin addresses is how to manage human population growth. Early in his essay, Hardin concisely described the conflict when he stated that "*a finite world can support only a finite population; therefore, population growth must eventually equal zero*" (p. 1243). The resolution to this conflict is observed when Harding concludes the paper by presenting his solution to the problem:

> *The only way we can preserve and nurture other and more precious freedoms is by* ***relinquishing the freedom to breed, and that very soon****. "Freedom is the recognition of necessity"- and it is the role of education to reveal to all the necessity of abandoning the freedom to breed. Only so, can we put an end to this aspect of the tragedy of the commons* (p. 1248).

Hardin's suggestion that humans reconsider reporoduction as a given freedom represents the narrative's resolution. He believes that if education is used to decrease the desire to breed, the problem of infinite growth in a finite space will be solved.

Two more important and related descriptive elements are *causality* and *agency*. *Causality* refers to the cause-and-effect relationships between the events, an element that occurs more often in narrative than other forms of communication (Dahlstrom, 2014; Zabrucky & Ratner, 1992). *Agency* is illustrated when events are put into motion by agents or characters in the story and occur for a reason and with consequence for the characters (Avraamidou & Osborne, 2009; Chatman, 1978; Norris et al., 2005; Toolan, 2001).

Both agency and causality are illustrated in the first chapter of the stream ecologist Kurt Fausch's autobiographical book For the Love of Rivers (2015). When describing a turning point in his career and life, he wrote:

> *During a reconnaissance trip, my graduate advisor* ***Ray White suggested*** *that we explore the stream by snorkeling, as a way of helping me gain firsthand experience in the environment of the trout that I would soon study. I* ***spent several hours underwater****, enthralled by what we saw, until I was too cold to dive anymore. On that day, the door to a new world had opened...* ***I first realized then****, without forming any clear thought, but only feelings, that this was a world I was drawn to understand. This was a place worthy of focused study, and these creatures could* ***fascinate me for a lifetime*** (p. 7-8).

The suggestion from Fausch's graduate advisor, and his willingness to follow the advice, demonstrate agency. The characters not only snorkel in the stream but make the choice to do so. Causality is illustrated by the fact that the snorkeling event leads to Fausch's career in stream ecology research. The rest of his story is shaped by a discrete event with long-lasting effects.

Characters are an important element of stories and are the agents who set actions into motion and are the focus of the conflicts and resolution. Because of this role, many narrative definitions include characters as a requisite element of the genre (e.g., Chatman 1978; Toolan 2001; Hinyard and Kreuter 2007; Kreuter et al. 2007; Dahlstrom 2014). Some definitions specify that the characters should be human, 'quasi-human,' or at least sentient (Norris et al., 2005; Toolan, 2001), while others do not stipulate the identity of the characters. A related narrative element is *setting*, which provides the scenery in which the characters are placed and the events occur (Hinyard & Kreuter, 2007). The setting also establishes the narrative's time, location, and primary characters (Thorndyke, 1977), providing the audience with much of the pertinent context in which action is occurring.

Both *characters* and *setting* can be observed in an excerpt from Aldo Leopold's A Sand County Almanc (1949) where Leopold describes the events that take place on his farm every spring.

> *When dandelions have set the mark of* ***May*** *on* ***Wisconsin pastures****, it is time to listen for the final proof of spring. Sit down on a tussock, cock your ears towards the sky, dial out the bedlam of the* ***meadowlarks*** *and* ***redwings****, and soon* ***you*** *may hear it: the flight-song of the* ***upland plover****, just now back from Argentine* (p. 67).

In these few sentences, Leopold establishes the characters and setting for the rest of his story. The characters include the meadowlarks, redwings, and the upland plover, along with the reader themselves. Leopold provides a clear setting for these characters as well. The narrative takes place during the month of May, just when the plover is returning. Additionally, the narrative is occurring at an identifiable location, specifically Wisconsin pastures, most likely near Leopold's farm. Leopold is able to quickly describe the framework for the rest of the story's events using these elements. While all of the descriptive elements are potentially observable during research, they are not all necessary when creating a research instrument. Some of these components are not unique to narratives, while others are only found in a subset of stories.

Proposed essential elements of narratives for research

The hypothetical and descriptive elements described above all have utility in different settings, but many of them may not be appropriate for empirical research. For this purpose, researchers need an instrument that can be applied across multiple studies, allowing us to determine when an artifact (e.g., a text or a lesson) is a narrative. If we cannot clearly and consistently delineate between narratives and other forms of communication, it is challenging to measure the effects of using stories to communicate science on audience understanding and/or perceptions of the content.

If scientists are to improve their communication skills with the general public, and if storytelling is an effective means to achieve this, it is essential to identify elements of stories that are relevant and likely to be present in science narratives. To this end, some elements were combined into more encompassing categories. For example, conflict and resolution are treated as a single element. It would be unreasonable to have a story that included a resolution with no conflict present. The following elements were deemed the most germane for the purpose of examining science narratives: events, characters, conflict/resolution, and causality/agency (Table 2). The description for each of these elements brings together the definitions from multiple authors, condensing their work into a more cohesive characterization. Elements that were removed from the proposed list for science narrative research include all of the hypothetical elements, as well as time and setting. While it is important for authors and communicators to consider these ideas when constructing a narrative, it is not inherently part of all storytelling.

The first essential element is the presence of *events*. The events need to be connected both temporally and in subject matter. Their temporal connection does not necessarily mean that they are presented in chronological order. In altering the discourse structure (the order in which events are presented), the authors can create greater drama by hiding and revealing information (Brewer & Lichtenstein, 1981; Glaser et al., 2009). In addition to their temporal connections, the events should also come together to create a larger meaning. The story as a whole should be greater than the sum of the events. Although Norris et al. (2005) and Moffett (1968) posited that the events presented in stories needed to be unique and unlikely to transpire again, this is not essential to a narrative. For example, a story could be written about an ordinary walk in the woods, where nothing unusual occurs. Hence, novel and unusual events alone do not define a story.

Characters in a narrative are the actors in the story's events. Their goals, motivations and desires are often the focus of the story. The actions of the characters set the events into motion, an idea that also appears later in the element of *agency*. The characters do not necessarily need to be human or quasi-human, as proposed by some authors (e.g. Toolan 2001, Norris et al. 2005). A story can be told that focuses entirely on non-sentient characters. However, most characters do engage in some type of *conflict and resolution*. The conflict includes unanswered questions, as well as obstacles in the path of the characters as they attempt to reach their goals. The resolution contains answers and solutions that are revealed due to the actions and choices of the characters.

The final element brings together *causality and agency*. Causality refers to the connection between different events in the same story. Event A leads to Event B, which causes Event C. These events do not have to be presented in chronological order, but their causal relationships should still be apparent. When events are put into motion by the story's characters and agents, they demonstrate agency. Events do no not occur randomly; they are clearly connected to the actions of the characters, and in turn lead to either further conflict or an eventual resolution.

These four elements include the majority of descriptive narrative components found in the literature. Missing from the list of essential elements are time and setting, yet these are implicitly included in the element of events/causality. Both Norris et al. (2005) and Avraamidou and Osborne (2009) argued that stories occur in the past; however, stories may be written in present or even future tense. For example, Leopold's A Sand County Almanac (1949) tells a series of stories about nature, all written in present tense. In the *January* chapter Leopold writes

"A rough-legged hawk comes sailing over the meadow ahead. Now he stops, hovers like a kingfisher, and then drops like a feathered bomb into the marsh" (p. 4). Leopold uses the present tense, adding to the reader's sense of being there for the events rather than just hearing a retelling.

Setting is often included in story elements because it establishes the time and location for the events and characters. It acts as the backdrop for everything that occurs within a narrative. Other forms of communication, though, use settings. Darwin's *On the Origin of Species* (1859) is an example of an expository text that provides historical, conceptual, and environmental contexts for his claims. Therefore, setting is not necessarily unique to narrative texts.

Conclusion

When considering the problems facing scientists and science communicators, narratives offer a strong possible solution to these challenges. They allow audiences to approach the content material in new ways and can increase learning. While many pieces of science writing, from the standard research article to some of the most influential essays, already engage in storytelling, by better understanding how the elements of storytelling are employed, scientists can improve the quality of their communication. Moreover, identifying the elements will allow scientists to fully understand what differentiates stories from other styles of communicating. Currently, the lack of clear consensus on what makes up a narrative and how to define essential elements, inhibits studying the impact of science storytelling. To address this problem, this paper describes a set of narrative elements that science communication researchers can use to engage in uniform narrative analysis.

Tables

Table 1. Narrative elements are described in diverse ways in the research literature. 'OR' indicates varying descriptions of the same element from different authors.

Category	Element	Description	Citations
Hypothetical	Narrator	Character who tells the story OR a general sense of a narrator	(Avraamidou & Osborne, 2009; Chatman, 1978; Downs, 2014; Norris et al., 2005; Toolan, 2001)
	Reader/ audience	Reader interprets text, based on expectations of stories.	(Avraamidou & Osborne, 2009; Chatman, 1978; Norris et al., 2005)
	Narrative appetite	Reader's desire to hear story	(Norris et al., 2005)
	Purpose	Helps audience to understand the world OR conveys some information OR communicates knowledge, feelings, values or beliefs	(Avraamidou & Osborne, 2009; Norris et al., 2005; Phelan, 1996; Schank & Berman, 2002)
	Theme	Focus of the story, goal of the main character	(Thorndyke, 1977)
	Identifiable structure	Stories should go somewhere OR beginning, middle, and end OR start with imbalances and end in resolution	(Avraamidou & Osborne, 2009; Hinyard & Kreuter, 2007; Kreuter et al., 2007; Norris et al., 2005; Schank & Berman, 2002; Thorndyke, 1977; Toolan, 2001)
Descriptive	Events	Connected temporally and used to create greater meaning OR unlikely to transpire again	(Avraamidou & Osborne, 2009; Chatman, 1978; Kreuter et al., 2007; Moffett, 1968; Norris et al., 2005; Taylor, 1982; Thorndyke, 1977; Toolan, 2001)
	Time	Past events OR events in a discrete time span OR retelling of an experience	(Avraamidou & Osborne, 2009; Dahlstrom, 2014; Downs, 2014; Norris et al., 2005; Schank & Berman, 2002; Toolan, 2001)
	Conflict	Early conflict or unanswered questions	(Hinyard and Kreuter 2007, Downs 2014)
	Resolution	Resolution reached through actions of the characters	(Downs, 2014; Hinyard & Kreuter, 2007; Thorndyke, 1977)
	Causality	Cause-and-effect relationships between events	(Dahlstrom, 2014; Zabrucky & Ratner, 1992)
	Agency	Events put into motion by characters	(Avraamidou & Osborne, 2009; Chatman, 1978; Norris et al., 2005; Toolan, 2001)
	Characters	Agents who set actions in motion OR humans/ quasi-humans	(Chatman, 1978; Dahlstrom, 2014; Hinyard & Kreuter, 2007; Kreuter et al., 2007; Norris et al., 2005; Toolan, 2001)
	Setting	Scenery for characters/ events OR establishes time, location and primary characters	(Hinyard & Kreuter, 2007; Thorndyke, 1977)

Table 2. Essential elements of narratives.

Element	Description
Events	A series of events that are connected both temporally and in subject. These events can take place sequentially or out of chronological order. Create a greater meaning together
Characters	Actors in the events. Their goals are the focus of the story
Conflict/ resolution	Characters encounter obstacles or questions in the course of the events. Answers and solutions are reached by the end through the actions of the characters
Causality/ agency	Events are put into action by the decisions and exploits of the characters. The events have a causal relationship with one another and lead to consequences for the characters.

CHAPTER 2: EFFECTS OF NARRATIVES ON GRADUATE TEACHING ASSISTANTS

Introduction

Science communication is increasingly being recognized as important but is unfortunately often poorly conducted (Treise & Weigold, 2002). Communication allows scientists to share their studies with the rest of the world, making their work more relevant while also increasing excitement for the sciences (Treise & Weigold, 2002). Natural science researchers and specialized science communicators are two of the most common groups to engage in communication. Researchers frequently lack the training and are unable to bridge the language divide that exists between the general public and the scientific community (Hartz & Chappell, 1997; Treise & Weigold, 2002). However, when scientists depend on the media or science communicators to deliver their findings, they are often frustrated by how their results are conveyed (Hartz & Chappell, 1997). The problems with communication can be seen in undergraduate science classrooms, where members of the public (students) directly interact with developing (graduate students) and expert (professors) scientists.

One possible solution to the issues described above is to incorporate narrative, rather than expository, communication strategies into science lessons. Expository communication differs from narratives in that it conveys information while limiting the opinions or storylines found within narratives (Balgopal & Wallace, 2013; Klassen, 2009). Narratives allow scientists to break through initial barriers, attracting a more diverse audience and including people who might initially feel that science is unapproachable (Avraamidou & Osborne, 2009; Kreuter et al., 2007; Mutonyi, 2016). Because stories are a familiar format to most people, they can access unfamiliar science content without stepping outside of their comfort zone (Prins, Avraamidou & Goedhart, 2017). In addition to slowly introducing the audience to the content, narratives can increase both learning and retention (Maria & Johnson, 1990; Negrete, 2003; Prins et al., 2017; Schank & Berman, 2002). The audience is able to more effectively extract relevant information, as well as visualize the concepts and events described in a story (Prins et al., 2017; van Haneghan et al., 1992). While these benefits seemingly make narratives the ideal solution for instructional delivery, the effects of narratives in formal settings is widely understudied. There has been a recent call for research examining the different impacts of narrative and expository writing on how audiences understand science (Klassen, 2009; Norris, Guilbert, Smith, Hakimelahi & Phillips, 2005). Even 30 years ago, Bruner argued that once we have characterized a text based on its form and meaning, we will still need to study "how and in what ways the text affects the reader and indeed, what produces such effects on the reader…" (Bruner, 1986).

The literature on the effects of stories contains a wide array of definitions for what makes narrative distinct from other forms of communication, such as expository or explanatory. This study employed a definition of science narrative based on four essential elements: events, characters, conflict/resolution, and causality/agency (Chapter 1, Table 2). These elements distinguish narratives from other communication strategies. The *events* element refers to a series of incidents that are connected to one another both temporally and in subject matter. They can be presented in any order, but they need to work together to create a greater meaning. *Characters* are the agents in the story. They put the events into motion and their goals are often the focus of the narrative. *Conflict* represents the obstacles and questions that characters face throughout the course of the events, while *resolution* refers to the answers and solutions that characters reach through their actions. Finally, *causality/agency* describes the causal connections between different events and that these events are put into action by the characters. In turn, the events have consequences for those characters.

All instructors can incorporate narratives into their lessons, whether in recitation, laboratory, or lecture courses. This study examined narratives used in a laboratory section taught by Graduate Teaching Assistants (GTAs). GTAs often teach introductory science laboratory and recitation sections, affording them more direct contract with undergraduate students than faculty members at large universities have (Rushin et al., 1997). Sundberg, Armstrong, & Wischusen (2005) found that in 91% of research universities, GTAs acted as the primary lab instructors. Even at liberal arts colleges, only 71% of schools reported using faculty members for lab instruction (Sundberg et al., 2005). GTAs are often invested in their role as teachers due to the fact that many of them plan on having careers in academia (Sauermann & Roach, 2012). Despite this interest and the level of contact that GTAs have with undergraduate students, GTA communication training and professional development is largely ignored. A 1997 survey of universities found that 49% of institutions provided no teacher training for their GTAs (Rushin et al., 1997). Universities that did offer training often used pre-semester workshops as their primary professional development (Rushin et al., 1997). A more recent survey found that mandatory training has increased since 1997, but that the professional development mainly focuses on teaching policies and classroom management, rather than ways to increase the quality of instruction (Schussler, Read, Marbach-Ad, Miller, & Ferzli, 2015).

By failing to train GTAs in different instructional delivery strategies, the problems with science communication are likely to continue. Instructional delivery can have large impacts on how students perceive their abilities (Klein & Noe, 2006). In turn, undergraduates students who question their own abilities in the content area or who are only tentatively engaged in the material, are more likely to perform poorly or leave the major altogether (Carini, Kuh, & Klein, 2006; Kuh, Cruce, Shoup, Kinzie, & Gonyea, 2008). Student self-perceptions of knowledge and abilities can have varying implications for learning and performance, but can be a valuable measure of the effects of different instructional delivery strategies (Shen & Tam, 2008). For this study, we examined the effect of training GTAs using narrative communication as part of their normal preparation to teach about climate change and phenology.

Climate change and phenology

We selected the topics of climate change and phenology as the content area for this study for a number of reasons. Phenology examines the timing of animal and plan development and activities (Walther et al., 2002). The field of climate change impacts is particularly timely, with more than 10,00 peer-reviewed publications on the subject in 2017 alone (based on a Web of Knowledge search for the topic *climate change impacts*). Furthermore, as a global phenomenon, the subject of climate change is discussed in classrooms across a wide range of science subjects and age levels (Pruneau, Gravel, Bourque, & Langis, 2003; Shepardson, Niyogi, Choi, & Charusombat, 2009; Wise, 2010). While many lessons and studies on climate change may focus on broader impacts such as the effects on everything from ocean productivity to erosion rates (McNutt, 2013), discussing the impacts on the biological components of ecosystems offers a chance to incorporate the topic effectively into undergraduate biology classrooms.

Previous natural science research has shown that climate change may affect both species' ranges and phenologies (Parmesan, 2006; Parmesan & Yohe, 2003). This is due to the predicted increase in variation of temperature and precipitation (Walther et al., 2002). The phenologies of insect pollinators have already been shown to be impacted by varying temperature regimes (Sparks & Yates, 1997). Many insects are ectothermic or poikilothermic, meaning that they are sensitive to changes in ambient temperatures (May, 1979). Plant-pollinator phenologies are susceptible to climate change, as the established relationship is often reliant on short time periods when flowers have developed and pollinators are present (Memmott, Craze, Waser, & Price, 2007). Climate change, and its associated altered temperature regimes, can lead to temporal gaps in the presence of pollinators and the development of their floral resources (Visser & Both, 2005). These phenological mismatches are likely to occur when plants and their insect pollinators are differentially affected by changes in temperature (Memmott et al., 2007).

Conceptual framework

This study is situated in the discourse and language theories developed by Lev Vygotsky and Jerome Bruner. Vygotsky (1978) created the framework of socio-cultural theory, focused on the idea that humans construct knowledge and make meaning through interaction with one another. In education this often refers to the interaction between the student and the instructor within the classroom (e.g., Kawalkar & Vijapurkar, 2011), but in science communication this can be used to understand the relationships between scientists and the public, or the narrator and the audience. Bruner developed Vygotsky's ideas for narratives and stories, theorizing that interaction between the writer and the reader allows the reader to form their own "virtual text," guided by the original document (Bruner, 1986). He argued that there were three ways a narrative could foster this interaction and discourse: presupposition, subjectification, and the incorporation of multiple perspectives.

The use of presupposition within a narrative allows the writer to create implicit meanings, rather than explicitly stating everything. Bruner (1986) purported that there were a series of triggers that a writer could include that would lead to a reader inferring meaning from the text, all of which would end in greater interaction between the author and the readers. The second strategy for developing discourse is the use of subjectification. This technique involves depicting the reality of the narrative through the eyes of one of its protagonists, rather than an omniscient third-person narrator. Subjectification can occur when an author uses narrative transformations (Todorov, 1977), to turn expository facts into subjective statements. Examples of transformations include changing the mode of a phrase by adding subjective terms such as *must, might, could,* or *would*, or placing an action within its intention (Todorov, 1977). The third strategy for producing interactions between the writer and reader is to include multiple perspectives. By presenting the world of the narrative through a series of lenses and possibilities, rather than as a single univocal reality, the audience is forced to work along with the text to understand the narrative (Bruner, 1986).

Bruner described two modes of thought, the logico-scientific and the narrative (Bruner, 1986). He described the first mode as an "austere but well-defined world" (Bruner, 2002) that focuses on describing and explaining the world through hypothesis testing (Bruner, 1986). Contrastingly, narratives exist in a "darkly challenging world" (Bruner, 2002) and aim to convince the audience of their verisimilitude (Bruner, 1986). This goal can be particularly difficult because, when compared to logico-scientific writing, readers often feel that stories too easily contain ulterior motives (Bruner, 2002). This is potentially an unfair assessment of narratives due to the fact that all language, whether used in a story or an exposition, foists a perspective of the world it is describing onto the reader (Bruner, 1986).

Research questions

While other studies have demonstrated the effects of direct narrative communication on students in classrooms, this study primarily seeks to understand the impacts of storytelling on GTAs and their instructional delivery. The questions guiding this study are:

RQ1: What elements of storytelling do biology GTAs exhibit after participating in training on either narrative or expository delivery of climate change and phenology?

1a. Which narrative elements are exhibited?

1b. When do GTAs demonstrate the use of narrative elements?

RQ2: What motivates biology GTAs to use elements of storytelling in their instruction on climate change and phenology?

RQ3: How does training on instructional delivery of climate change and phenology affect GTAs' content knowledge and self-perceptions of that knowledge?

RQ4: How does storytelling affect the self-perceptions of undergraduate students regarding their knowledge of climate change and phenology?

Methods

This multiple methods study used both qualitative and quantitative analyses to answer the related research questions (Glesne, 2006). Research questions one and three were answered using a combination of qualitative (e.g., videos of GTA lessons) and quantitative (e.g., numerical survey responses) data. Research question two was addressed using only qualitative data (GTA interview transcripts). Finally, research question four was answered using only quantitative data (undergraduate survey responses). By using multiple sources of data and types of analyses, we were able to triangulate our results using several forms of evidence.

Setting and participants

This study took place in an introductory biology laboratory course at a large (~25,00 undergraduate students) research-intensive university in the Western United States. The course focuses on introductory plant and animal anatomy and physiology. The intervention was incorporated into an ecology lesson with content that included an owl pellet dissection, and discussions of food webs and trophic levels. The research was conducted over the span of two consecutive semesters, starting in the spring, with only minor differences in methods between the two trials. During the semesters when this study took place, there were a combined 31 lab sections, 636 enrolled undergraduate students, 17 teaching assistants (16 graduate students and one undergraduate hired as GTAs). Nine of the lab instructors were female and eight male; 16 identified as White and one as multi-racial; and all 17 were enrolled in science programs (six in PhD programs, ten in master's programs, and one in a bachelor's program) (Table 1).

Intervention: Training on phenology instruction

As part of the training intervention on different instructional delivery strategies, two PowerPoint presentations were created. The content of both presentations focused on plant pollinator phenology and climate change. Both presentations included an explanation of phenology, a brief summary of historical phenological research, a case study on the National Cherry Blossom Festival in Washington, D.C., and a description of cherry tree pollination. For the spring semester, the presentation was built primarily as a lecture, with few explicit opportunites for student interaction. During the fall semester, the intervention included moments designed to foster student involvement, modeled after a typical lesson taught in this course, rather than a strictly monologic presentation. This meant incorporating slides into the presentations that prompted students to spend a few minutes drawing connections between the content and their previous experiences, before sharing those connections with the class. In each semester, one intervention used narrative communication elements, and the other was designed to be expository. The presenter notes differed for each set of slides: the narrative version incorporated the essential elements of narratives, while the expository presentation had fewer of these elements. For example, the narrative intervention notes on historical phenological research presented the information so that the actions of the researchers were in response to their interests and motivations. The expository intervention notes presented this same information without the causal connections between the interests and actions.

The consenting GTAs were divided into two intervention groups with ten participants in the narrative group and seven in the expository. They attended their normal weekly GTA preparation meeting but were separated when they learned about the ecology/phenology content. The trainer (one of the co-authors) modeled the phenology lesson during these sessions. To ensure that each GTA training session included the appropriate level of narrative elements into each lesson, these were video-recorded and reviewed before the data were collected from GTA laboratory sections. Each GTA was sent a copy of the lesson slides from the training session, including the presenter notes.

Data collection

Three sources of data were collected in this study: (i) video recordings of each class, (ii) GTA interviews, and (iii) pre-post surveys about self-perception of understanding of climate change/phenology for GTAs in both treatment groups and their respective students.

During the week following the training intervention, GTAs taught their phenology lesson and were video-recorded. Most GTAs taught two lab sessions, although due to scheduling complications several taught one or three classes. In the week after the post-intervention survey, each GTA was interviewed using a semi-structured protocol. Interviews lasted between seven and 28 minutes, were audio-recorded, and focused on the experiences and instructional decisions of each GTA. All audio-recordings were transcribed.

A short survey created for this study was administered to both GTAs and undergraduate students before instruction, as well as the week following the intervention. The survey was meant to assess the perceptions of participants' content knowledge of climate change and phenology material (Appendix B). During the fall semester, the items on the survey were a combination of Likert-scale closed response items (five) and open response items (three) that referenced the laboratory activities and discussion. The post-intervention survey was identical but also included two questions asking participants to assess the effects of their phenology lessons (Appendix B). The spring semester survey included the same closed response questions but was missing the open response items found in the fall. The survey was intended to generate triangulating data to support the analysis of the video-recordings and GTA interviews.

Data analysis

For the analysis of the GTA lessons, video-recordings were divided into four segments based on content areas and analyzed separately. For each segment, the presence or absence of each of the essential narrative elements was coded, resulting in a total of 16 possible narrative element occurrences in each presentation. This protocol was repeated with the video-recordings of the training sessions. Because most of the GTAs taught two lessons which were not wholly independent of one another, we analyzed the video data using a series of two-factor repeated measures ANOVAs in R (R Core Team, 2018). These ANOVAs allowed us to account for the likely correlation between the presentations given by each GTA, while also examining differences between the two intervention groups. ANOVAs were run to compare 1) the total number of element occurrences and 2) the occurrences of each individual element across the two groups of GTAs. In addition, each instructional segment was analyzed separately to determine when GTAs were most likely to incorporate narrative elements.

GTA interviews from the fall semester were analyzed iteratively using the protocol described by Braun and Clarke (2006). Initally a series of memos for each interview were recorded to identify relevant terms and phrases regarding phenology content knowledge and instructional delivery strategies. These were systematically collapsed and categorized, until we created 15 open codes (Table 2). These open codes included GTA discussion of how they made decisions regarding their instructional delivery, what they perceived as broad goals for their delivery, as well as their content knowledge in the area of phenology and climate change. We then collapsed these open codes into five axial codes (Table 2), which we developed into propositions in response to the research questions.

The closed responses on the survey for both semesters were transformed into numerical values using a Likert scale: *A,* representing the highest level of confidence in their own knowledge, was transformed to 5, *E,* representing the lowest level of confidence, was transformed to zero, and *F* ("I don't know") was considered neutral and was therefore coded as a three. Student t-tests were run to test the hypotheses that responses on the post-survey would be higher than on the pre-survey and that responses in narrative lab sections would be higher than in expository sections. For the open response knowledge questions from the fall, we created a set of qualitative codes for the answers to each of the questions (Table 3). These codes were generated in a similar fashion to the interview analysis and were based on the answers provided by the GTAs. We generated two or three codes for each question, which encompassed all of the GTA responses (Table 3).

Findings

The findings are presented in three sections: *what* elements of narratives were exhibited by GTAs, *why* GTAs made decisions about instructional delivery, and *how* participation in the training on instruction affected the self-perceptions of the GTAs and their undergraduates.

GTA instructional delivery and integration of narrative elements

The interventions had significant effects on how the GTAs taught their lessons on climate change and phenology. GTAs in the narrative group used significantly more narrative elements than the GTAs in the expository group ($p<0.001$, Figure 1, Table 4). The narrative group GTAs used an average of 13.7 element segment occurrences per lesson, compared to an average of 8.5 in the expository group GTAs. The narrative GTAs were also more likely to use both *causality/ agency* and *conflict/ resolution* when compared to the expository group (Figure 1, Table 4).

Some elements were more frequently observed than others. The difference between the two intervention groups was greatest for the element, *causality/ agency*. The narrative GTAs used that story element 6.4 times more frequently than the expository group. Both groups of GTAs were equally likely to incorporate *characters* ($p=0.117$) and *events* ($p=0.133$) into their stories, with no significant difference found between the two interventions.

Across both intervention groups, there was a high level of fidelity of instructional delivery to what GTAs observed during the training session (Figure 1). They included similar numbers of narrative elements in their lessons, compared to the training lesson that they were a part of. This finding aligns with the fact that all five of the fall GTAs commented that they attempted to emulate the presentation that they witnessed during the intervention. Finn said that he "*tried to model [the trainer] and give [the lesson] in a similar way.*" Julia described her instructional delivery as "*trying to emulate how [the trainer] presented it to us.*"

While none of the fall GTAs specifically identified any narrative elements from the interventions, they were able to incorporate them into their own lessons. The GTAs in the narrative intervention incorporated narrative elements across their lessons; however, elements were observed more often in some instructional segments than others (Figure 2, Table 5). The narrative group GTAs used almost the complete set of four elements in the segments on historical phenological research (3.39 elements), the national cherry blossom festival (3.83 elements), and the example of cherry tree phenology (3.72 elements). The greatest difference between the two intervention groups took place during the segment on historical research. The narrative GTAs used 1.9 times as many narrative elements as the expository GTAs ($p<0.001$). This difference is accounted for by the fact that the expository GTAs were less likely to incorporate *causality/ agency* or *conflict/ resolution* into this segment. The narrative GTAs described the questions that the researchers faced, how they went about investigating phenology, and ultimately what conclusions they reached. In other words, through narrative instructional delivery, these GTAs described the process of scientific inquiry as well as the results. This excerpt from Maddie's instruction demonstrates how she incorporated the intentions and motivations for scientists who were curious about phenology.

> "*[Carolus Linnaeus] was really interested in phenology and the effect of climatic conditions, but also wanted to know if there were any patterns in these appearances. So, he compiled a lot of his observations in the Philosophia Botanica, published in 1751. He created this whole methodology for recording leaf opening, flowering, fruiting, leaf fall, along with observations of climate that were happening with those events.*"

In contrast, the expository GTAs presented that the researchers looked at an area of phenology and produced a particular work or result, but they left out the motivations and the connections between events and characters. In the process, the focus of their instruction was on the findings of the research, rather than the investigative processes. They discussed what scientists had accomplished, while leaving out the motivations to study phenology, as Karla's excerpt illustrates:

> "*So, Carolus Linnaeus was a scientist in the 18th century and he wrote the Philosophia Botanica. He's known as the Father of Taxonomy. So, he was the one that originated the taxonomy scheme using the Latin words… He also compiled methods for tracking plants. So looking at dates of leaf opening, flowering, fruiting and leaf fall.*"

Without including *character agency* and *causal relationships* between the events, it is very difficult for a story to move from *conflict* to *resolution*. Therefore, students in the expository classes were more likely to hear about the "whats" of science, compared to the narrative classes that likely heard about both the "whats" and "whys" of scientific study.

GTA instructional decisions and motivations

GTAs' instructional intentions were described during their interviews. Many of them explained that they attempted to mirror or emulate the delivery strategies they had observed during the training. William explained that he "*tried to sort of emulate what [the trainer] had done as best as I could… like the general flow of how [he] went through the information…*" Maddie concurred, "*I think I ended up giving a fairly similar [lesson]... It was good to hear it first and then just kind of think back to 'what did [the trainer] do?'*"

While they did not explicitly describe the use of narrative elements during their interviews, several of the GTAs discussed why they chose to include stories in their lessons. They explained that stories enable both the instructor and the students to make personal connections to the content, something that makes the information more relevant and memorable. Maddie explained, during the interview, that using stories "*... connects both me and anyone I'm talking to to the material a little bit better, like it makes it more personal and relevant to have that kind of emotional connection.*" William also felt that using stories "*... makes it a little more personalized and helps build connections.*" He also pointed to his perception that storytelling increased his students' enthusiasm for and accessibility to the content material. "*They always seem to get interested talking about field experiences and stuff like that. And they get excited over that stuff."* In fact, William believed that by making the content accessible to students, he made himself more accessible: "*... it seems that they find me more approachable that way too. As opposed to like kind of here's the information.*"

Even the GTAs who did not engage in storytelling per se noted the importance of making the content more relatable. Karla, the instructor who incorporated the fewest number of narrative elements, still included anecdotes about her personal research. When asked about her style of communication, she said, "*I mean I go more lecture style, but I also try to make it personal and relatable. Like I try to bring in my experiences and just add to it with what I'm knowledgeable of.*" These asides often focused on areas that were not directly related to the content of the lesson and allowed her to integrate her research interests and content expertise. The majority of the elements that Karla incorporated existed in these anecdotes.

Content knowledge (phenology and climate change)

Many of the GTAs reported that they did not feel confident or knowledgeable about phenology or the effects of climate change on biological organisms. When explaining why they chose to emulate the lessons that the trainer gave, several of the GTAs in both groups described that they were less comfortable with the phenology material than some of the other information they teach in the laboratory curriculum. They were therefore less likely to make changes to the presentation. For example, Julia indicated that she felt it was appropriate to mimic the training presentation because she was not confident in her content knowledge: "*I think I was a little bit more, I want to say rigid because it's not really an area that I normally teach... I don't want to steer them wrong or present wrong information.*"

Some of this discomfort may have been due to the fact that the area of phenology was more conceptual than the other topics taught in this lab course. Maddie described the concept of phenology as being "*... a bit broader than some of the specific things that we talk about in that* *lab. Like we talk about how cephalopods have closed circulatory systems.*" She pointed to the fact this course often focused on more discrete pieces of information that students needed to memorize, rather than phenology that was a *"a little bit more abstract for some people.*"

GTAs in both intervention groups believed that the lesson that they had received had increased their knowledge of phenology (Figure 3). Interestingly, analysis of the open-response questions for the fall GTAs shows that there was little change to the content knowledge in either intervention group. For example, in the pre-intervention responses to the question, *what are some environmental cues that might impact the timing of biological events?,* all of the GTAs answered with plausible abiotic factors (e.g., *photoperiod*, *temperature*, and *wet/ dry seasons*) that could act as cues. Although they may not have believed that they had an understanding of phenology, they were all able to draw from prior knowledge to answer the question.

Despite the lesson's focus on presenting phenology as an important aspect of climate change, the GTAs believed that the lessons did not increase their knowledge of the latter subject. These results imply that GTAs viewed the areas of climate change and phenology as distinct. Although this concept was not examined further in this study, it warrants further exploration in future research.

The undergraduate student surveys showed similar, but more statistically significant, trends to the GTAs (Figure 4). Their self-percieved knowledge of phenology and pollination increased after the intervention, although there was no significant change for their knowledge of climate change. In the two cases where there were significant differences between the intervention groups (post-intervention knowledge of climate change and the effects of the lesson on knowledge of phenology) the students in the expository group had values than the narrative group.

The one open-response question where there was a marked improvement for the fall GTAs asked *what's one way that phenology could affect the owl food webs we just looked at?* Immediately prior to the interventions, the GTAs had been told how to present information about ecology, food webs, and trophic levels using owl pellet dissections to survey prey. Four of the GTAs responded to this question with answers that focused on trophic cascades similar to Maddie's response:

> "*A disruption of the seasonality of certain plants could disrupt insect activities, which in turn could disrupt when primary consumers can get food/ their ability to survive, and cause a cascade of events up to higher levels of the food chain/ trophic hierarchy*"

In their post-intervention responses, all three of the narrative GTAs changed their answers to focus on the phenological mismatches discussed in the lessons. An example of this change is found in Maddie's post-intervention response: "*A phenological mismatch caused by climate change between different trophic levels could cause an animal/ insect to miss out on a food source and/or plants to miss out on pollination service*"

Discussion

Much of the current literature on science teaching at the undergraduate level centers on making content more engaging because it has been demonstrated that active learning strategies are correlated with increased gains in content knowledge, competencies in quantitative and scientific reasoning, and motivation to continue studies in the sciences. However, most of the literature focuses on active learning strategies, such as problem-based learning and small group work. One under-examined strategy is engaging storytelling during instructional presentations. The current study examined how GTAs who were trained in either narrative (storytelling) or expository approaches to instruction during a laboratory section on climate change and phenology were affected in terms of instructional strategies, decisions, and confidence in content knowledge, as well as the self-perceptions of their undergraduate students. We found that GTA training had a positive effect on instructional strategies used, although the motivations to use these strategies and the perceptions of their own content knowledge were similar across both groups.

The narrative group GTAs integrated more narrative elements in their instruction than the expository group of GTAs. One possible explanation for the disparity between the two groups of GTAs (narrative vs expository) is that the narrative group more often integrated causality/ agency into their instruction, and this element encompasses several other narrative elements. For causality/ agency to appear, there need to be *events* with a causal relationship, as well as *characters* who act as agents, putting the events into motion. Additionally, causality/ agency can be important for the final element of *conflict/ resolution*. By being deeply connected to the other narrative elements, causality/ agency may act as a narrative indicator or keystone, resulting in the large difference in usage between the expository and narrative GTAs.

Characters was one of the most common elements that both groups of GTAs incorporated throughout their lessons. This high frequency makes sense in the context of a biology course where instructors are accustomed to describing characters as the focus of their lessons, especially if we adopt a broad definition of characters that includes organisms, single cells, or even molecules. In integrating causality/ agency and characters, the narrative group GTAs were more likely to describe a more holistic process of scientific inquiry than the expository group GTAs. Characters have agency in these science narratives, and when the characters are inquisitive and curious, GTAs can describe the motivations of those engaging in scientific study. These are, in fact, the goals for instructors that have been well documented in

National Research Council documents (e.g., National Research Council, 2012). They argue that in order for students to understand how scientific knowledge is generated, instructors should focus on why scientific practices are done, as well as the iterative and refining nature of inquiry, rather than a singular “scientific method” (National Research Council, 2012).

Previous studies have shown that many GTAs are invested in their teaching responsibilities due to their planned careers in academia. The GTAs who volunteered to participate in this study expressed varying levels of interest in engaging their students. Some recognized that increasing students’ excitement and enthusiasm for science content is important because it is associated with increased learning outcomes, motivations to learn, and intentions to persist in science (e.g., Maria & Johnson, 1990; Prins et al., 2017). Other instructors focused on making the material accessible to their students. Instructors’ interactions with students and their instructional delivery is important in raising students’ enthusiasm for content (Patrick, Hisley, & Kempler, 2000; Zhang, 2014). Furthermore, stories provide an opportunity for GTAs to share research experiences that they are passionate about, helping students appreciate what motivates scientists to pursue their studies.

We argue that science storytelling makes science more accessible to students when they are exposed to the motivations and the emotive responses to scientific investigations (frustration from failures, persistence due to curiosity, and excitement over discoveries) (Gilbert, Hipkins, & Cooper, 2005; McNett, 2016). These details allow students to view scientists as real people conducting approachable human activities that the students themselves are capable of (Gilbert et al., 2005). Gilbert et al. (2005) argue that by including the motivations and feelings of researchers, students are able to identify with the scientists. Others posit, likewise, that stories make science less intimidating for students (e.g., Avraamidou & Osborne, 2009; Mutonyi, 2016).

Although not part of this study, an examination of emotive elements in instructors' (in this case, GTAs) presentations is warranted.

Like motivations for engaging students, there were not any discernible differences between the intervention groups in terms of the GTAs' content knowledge after participating in the training. Both groups of GTAs demonstrated gains in phenological content knowledge. This is likely due to their original unfamiliarity with the area of phenology, especially in relation to climate change. Several of the GTAs reported having not learned this content prior to our intervention, despite the fact that they all perceived themselves as having a strong grasp of climate change content. This indicates that as a lesser known component of climate change effects, phenology was the subject where knowledge gains could most readily occur. Interestingly, Lawrence (2009) argued that informal studies or observations of phenological changes are important and powerful ways for the public to understand climate change. Moroever, Lawrence (2009) documented the emotive responses that people have when they describe shifts in biological events over time. The fact that the GTAs in the current study were not familiar with phenology presents an opportunity for professional development of biology laboratory instructors.

The undergraduate students who were taught by the expository GTAs had greater self-perceived knowledge and believed that the lesson had a larger impact on their understanding of phenology when compared to the students in the narrative intervention group. This finding does not align with the current literature on the effects of storytelling on students (e.g., Kreuter et al., 2007; Prins et al., 2017; Schank & Berman, 2002; Zabrucky & Ratner, 1992). One possible explanation for these results is that our intervention took place during a single lesson, rather than over the span of a semester. For many of the students, this was likely their first time being taught in the form of stories, and they may have been uncomfortable or unfamiliar with narratives in a formal classroom setting. Although research on the effects of brief versus extended educational interventions has yielded varying conclusions (e.g., Baker et al., 2011; Lambert, 2001), it is a factor worth considering. Future research is needed to investigate this area of our findings, either through interviews with the undergraduate students or by extending the timespan of the study.

As climate change science is a frequent part of the national and global environmental discourse, it is important for graduate students to feel prepared to integrate it in their instruction (Boykoff & Roberts, 2007). The fact that the effects of climate change on natural disasters, biodiversity, economy, and policy are discussed in the news on a daily basis justifies the missed opportunity to integrate a current event topic into a foundational course (Boykoff & Roberts, 2007). For biologists, one of the most obvious connections between the content in a foundational organismal biology class and climate change is phenological changes and mismatches. The findings from this study point to the limitations in the biology GTAs knowledge of this content. There are clear opportunities for professional development on how to integrate climate science into this 100-level course.

In addition to discussing phenology, there are multiple openings to incorporate climate change and narratives into introductory biology classes. Lessons on areas such as habitat loss or plant development are examples of moments when stories about the effects of climate change can be woven into the existing material. Courses in botany, entomology, ecology, geology, and atmospheric science can all appropriately include climate change education in their lessons. Hopkins (2013) found that New Zealanders drew on local, place-based examples to understand phenology and when they could do so, would integrate their personal knowledge with scientific and policy knowledge. Classes outside of the natural sciences may use narratives to investigate subjects such as environmental journalism or public policy. Climate change is a broad and omnipresent issue outside of academia and should therefore have the same presence in our undergraduate education.

Stories have the potential to increase science learning, accessibility, and motivation to learn (and, thus, stay in the sciences). The current study focused primarily on GTAs, who have more contact with students in small laboratory/recitation sections than lecture instructors (most often faculty members or teaching track instructors) (Sundberg et al., 2005). This study demonstrates that GTAs who are trained using storytelling are more likely to continue with that strategy in their own classrooms and lessons. Therefore, it is likely that professional development for both lecture instructors and GTAs could have positive impacts on numerous outcomes. Furthermore, because the GTAs who used storytelling delivery were more likely to focus on the investigate process of knowledge generation, there are implications in how we can help undergraduate students improve their understanding of the nature of science. Abd-El-Khalick and Lederman (2000) found that explicit instruction on history of science and nature of science enhanced undergraduate students' understanding of how science knowledge is generated. In light of the public's hesitation to accept climate change, future examination of the use of storytelling delivery and how it may help students better appreciate how climate change data are collected and analyzed are important. In addition, narratives around climate science have the added potential to help students in introductory science classes to be more prepared to make sense of climate change news and policy outside of the course context. However, while this work primarily examined the effects of narrative training on GTAs, future research is needed to fully measure the impacts on undergraduate students.

Figures

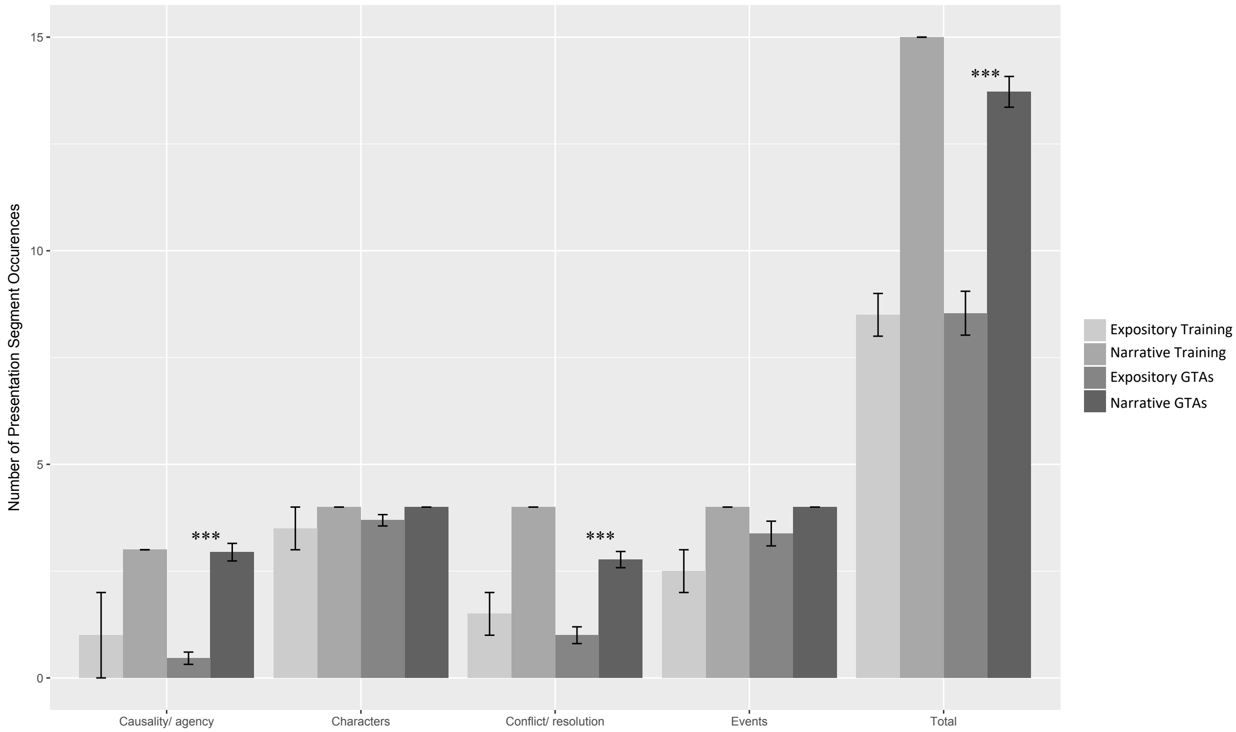

Figure 1. Narrative elements in training and GTA presentations. Error bars represent standard error. *** indicates a p-value < 0.001 when comparing expository and narrative GTAs.

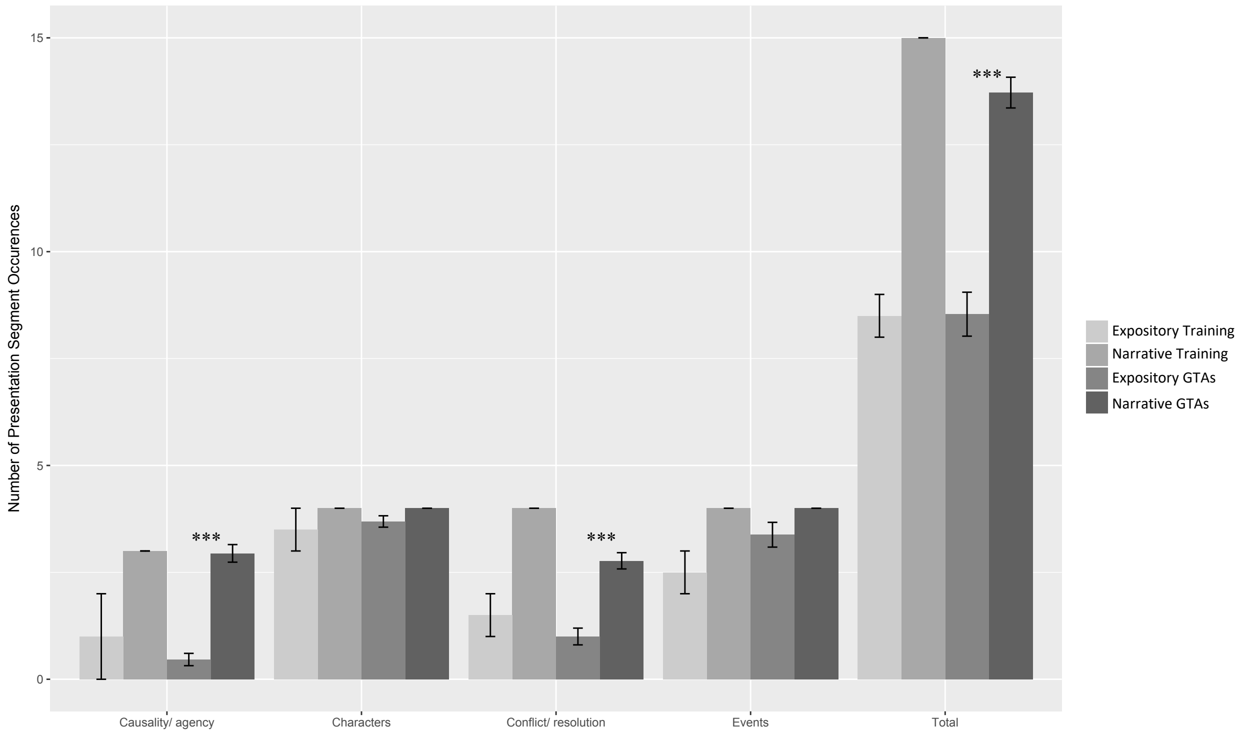

Figure 2. Narrative elements by lesson segment in training and GTA presentations. Error bars represent standard error. *** indicates a p-value <0.001 when comparing expository and narrative GTAs.

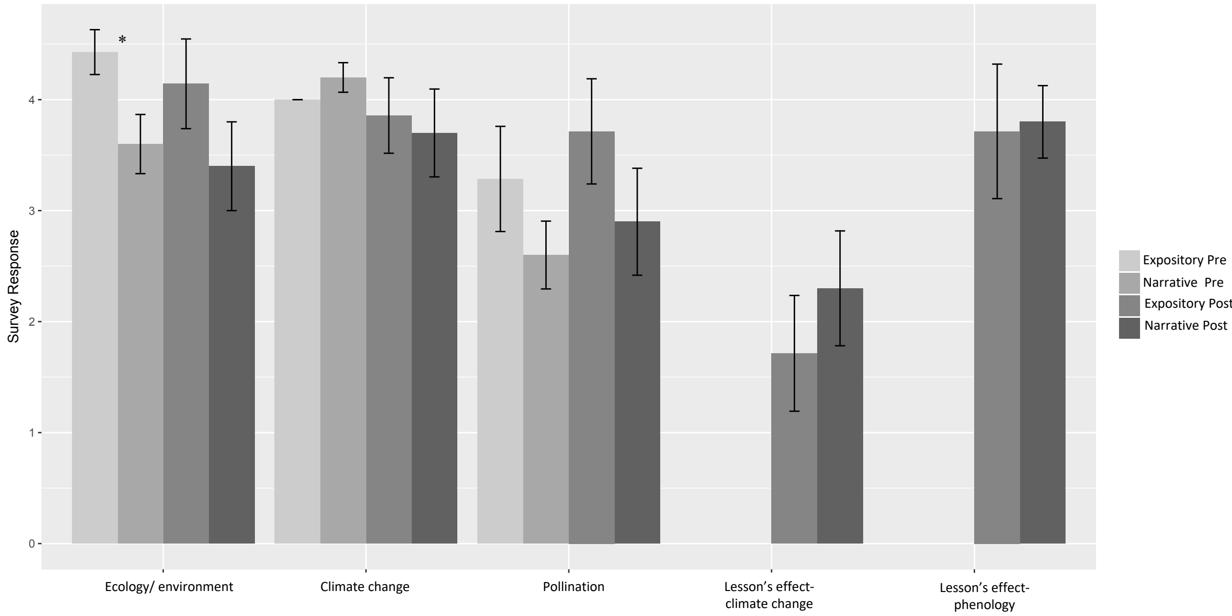

Figure 3. Results from multiple choice survey questions regarding GTAs' self-perceptions. Responses are based on a Likert scale, where a higher number represents a higher level of perceived knowledge or perceived effect of the lesson on knowledge. Errors bars represent standard error. * represents a p-value <0.05 when comparing intervention groups.

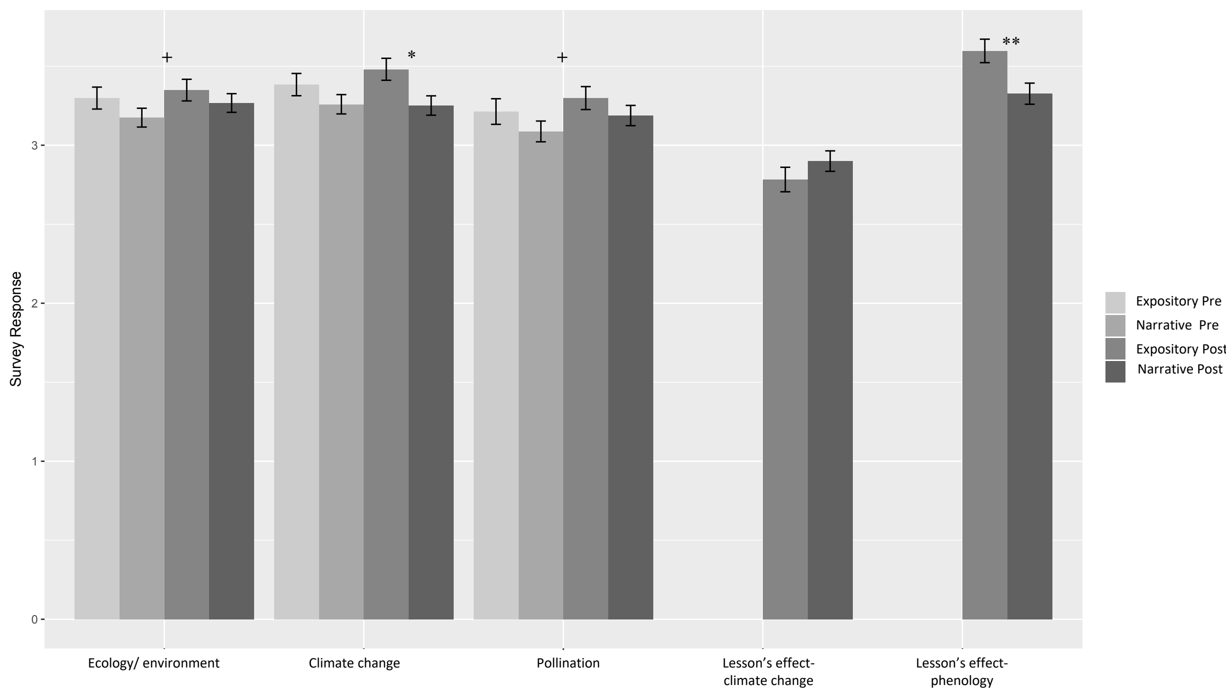

Figure 4. Results from multiple choice survey questions regarding undergraduate students' self-perceptions. Responses are based on a Likert scale, where a higher number represents a higher level of perceived knowledge or perceived effect of the lesson on knowledge. Errors bars represent standard error. * represents a p-value <0.05 and ** represents a p-value <0.01 when comparing intervention groups. + represents a p-value <0.05 when comparing pre- and post-intervention results for all students.

Tables

Table 1. GTA interventions and demographic information.

Intervention	Semester	GTA	Gender	Ethnicity	Department	Degree
Narrative	Spring 2017	Lois	Female	White	Biology	Professional Science Masters (PSM)
		Laura	Female	White	Biology	PSM
		Karen	Female	White	Biology	MSc
		Teresa	Female	White	Biology	PSM
		Paul	Male	White	Biology	Bachelor's
		Kevin	Male	White	Ecology	MSc
		Eric	Male	White	Biology	MSc
	Fall 2017	Maddie	Female	White	Biology	PSM
		Julia	Female	White	Environmental and Radiological Health Sciences	PhD
		Finn	Male	White	Bioagricultural Science and Pest Management (BSPM)	PhD
Expository	Spring 2017	Rachel	Female	White	Biology	MSc
		Ashley	Female	White	Biology	PSM
		Damien	Male	White	Ecology	PhD
		Ralph	Male	White	Biology	PSM
		Brian	Male	White	BSPM	PhD

Fall 2017	Karla	Female	Multiracial	Microbiology, Immunology, and Pathology	PhD
	William	Male	White	Biology	PhD

Table 2. Open codes, axial codes, and examples from GTA interviews for both areas of inquiry

Area of Inquiry	**Open Code**	**Axial Code**	**Examples**
Instructional delivery	Accessibility Connections Personal stories Relatability Relaxed	Accessibility	"*I was just trying to keep it maybe on their level without using so much terminology… I try to keep it in more laymen terms*"- Julia "*I just think [adding anecdotes] makes it a little more personalized and helps build connections*"- William
	Emulate Passive decisions	Emulate Trainer	"*I tried to model [the trainer] and give [the lesson] in a similar way*"- Finn "*I was like hmm I don't know, it's what I was told to do I'll just do it*"- Julia
	Confined Rigidity	Rigid	"*I don't know the purpose of your study, so I didn't want to modify it much*"- Karla "*I think I was a little bit more I wanna say rigid because [phenology is] not really an area that I normally teach*"- Julia
Content knowledge	Broader content More abstract	Broader	"*[Phenology is] a little bit broader than some of the specific things that we talk about in that lab*"- Maddie
	Lack of expertise Lack of ownership of material Uncomfortable Unfamiliar	Unfamiliar with content	"*I'm not very familiar with that research that science in that area. Like I don't want to steer them wrong or present wrong information*"- Julia "*It's not what I'm really knowledgeable about. So, it was different for me cause it's not my expertise*"- Karla

Table 3. Prompts, axial codes, and examples for open-response survey items. Results presented include the answers from pre- and post-intervention surveys.

Open response prompt	Axial Code	Example response
What's one way that phenology could affect the owl food webs we just looked at?	Phenological mismatch	*A phenological mismatch caused by climate change between different trophic levels could cause an animal/ insect to miss out on a food source and/or plants to miss out on pollination services*
	Trophic cascade	*Climate change impacting plant growth (sooner or later) thus impacting herbivore/ omnivore populations thus impacting owl populations. No plants, no herbivore/ omnivores therefore no food for owls. Therefore, owls affected.*
What are some environmental cues that might impact the timing of biological events?	Abiotic cues	*Seasons, temperatures, light and dark cycles*
	Mixture of biotic and abiotic cues	*Pheromones/ scents, day/ night cycle, colors, temperature/ seasons, water volume*
Describe a predictable biological event that's important to where you come from.	Biological and predictable	*Turning of the leaves in New England. The autumn foliage brings many tourists to New England*
	Abiotic and predictable	*Onset of winter/ snows*
	Biological and unpredictable	*New England continues to warm, and forest ecosystems are being altered particularly with more southern tree types that can be more dominant than colder weather tolerated trees*

Table 4. Number of segment occurrences for narrative element, comparing narrative and expository intervention groups. P-values are based on two-factor repeated measure ANOVAs comparing the two intervention groups.

Narrative Element	**Intervention**	**# of segment occurrences**	**p-value**
Events	Narrative	4.00	0.133
	Expository	3.38	
Causality/agency	Narrative	2.94	**<0.001**
	Expository	0.46	
Characters	Narrative	4.00	0.117
	Expository	3.69	
Conflict/resolution	Narrative	2.77	**<0.001**
	Expository	1.00	
Total	Narrative	13.72	**<0.001**
	Expository	8.54	

Table 5. Number of elements present in each presentation segment, comparing narrative and expository intervention groups. P-values are based on two-factor repeated measure ANOVAs comparing the two intervention groups.

Presentation Segment	Intervention	# of elements present	p-value
Phenology background	Narrative	2.67	0.180
	Expository	2.15	
History	Narrative	3.39	**<0.001**
	Expository	1.77	
Cherry blossom festival	Narrative	3.83	**<0.001**
	Expository	2.62	
Cherry blossom pollination	Narrative	3.72	**<0.001**
	Expository	2.00	

REFERENCES

Abd-El-Khalick, F. S., & Lederman, N. G. (2000). The influence of history of science courses on students' conceptions of the nature of science. *Journal of Research in Science Teaching*, *37*(10), 1057–1095.

Avraamidou, L., & Osborne, J. (2009). The Role of Narrative in Communicating Science. *International Journal of Science Education*, *31*(12), 1683–1707. http://doi.org/10.1080/09500690802380695

Baker, D. W., Dewalt, D. A., Schillinger, D., Hawk, V., Ruo, B., Bibbins-Domingo, K., … Pignone, M. (2011). The effect of progressive, reinforcing telephone education and counseling versus brief educational intervention on knowledge, self-care behaviors and heart failure symptoms. *Journal of Cardiac Failure*, *17*(10), 789–796. http://doi.org/10.1016/j.cardfail.2011.06.374

Balgopal, M., & Wallace, A. (2013). Writing-to-Learn, Writing-to-Communicate, & Scientific Literacy. *The American Biology Teacher*, *75*(3), 170–175. http://doi.org/10.1525/abt.2013.75.3.5

Boykoff, M. T., & Roberts, J. T. (2007). *Media Coverage of Climate Change: Current Trends, Strengths, Weaknesses*. *Human Development Report 2007/2008*.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(May 2015), 77–101. http://doi.org/10.1191/1478088706qp063oa

Brewer, W. F., & Lichtenstein, E. H. (1981). Event schemas, story schemas, and story grammars. In J. Long & A. Baddeley (Eds.), *Attention and performance IX* (pp. 363–379). Hillsdale, NJ: Lawrence Erlbaum.

Brossard, D., & Lewenstein, B. V. (2010). A critical appraisal of models of public understanding of science. In *Communicating Science: New Agendas in Communication* (pp. 11–39).

Bruner, J. (1986). *Actual Minds, Possible Worlds*. Cambridge MA: Harvard University Press.

Bruner, J. (2002). *Making Stories: Law, Literature, Life*. New York, NY: Farrar, Straus and Giroux.

Carini, R. M., Kuh, G. D., & Klein, S. P. (2006). Student engagement and student learning: Testing the linkages. *Research in Higher Education*, *47*(1), 1–32. http://doi.org/10.1007/s11162-005-8150-9

Carson, R. (1962). *Silent Spring*. Houghton Mifflin.

Chatman, S. (1978). *Story and discourse: Narrative structure in fiction and film*. Ithaca, NY: Cornell University Press.

Coulson, J., Whitfield, D., & Preseton, A. L. (Eds.). (2003). *Keeping things whole: readings in environmental science*. Great Books Foundation.

Dahlstrom, M. F. (2014). Using narratives and storytelling to communicate science with nonexpert audiences. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(Supplement_4), 13614–13620. http://doi.org/10.1073/pnas.1320645111

Darwin, C. (1859). *On the origin of species by means of natural selection, or, the preservation of favoured races in the struggle for life*. London: J. Murray.

Diasamidze, I. (2014). Point of View in Narrative Discourse. *Procedia - Social and Behavioral Sciences*, *158*, 160–165. http://doi.org/10.1016/j.sbspro.2014.12.062

Downs, J. S. (2014). Prescriptive scientific narratives for communicating usable science.

Proceedings of the National Academy of Sciences, *111*(Supplement_4), 13627–13633. http://doi.org/10.1073/pnas.1317502111
Egan, K. (1986). *Teaching as story telling: an alternative approach to teaching and curriculum in the elementary school*. London, ON: Althouse Press.
Fausch, K. D. (2015). *For the Love of Rivers*. Corvallis, OR: Oregon State University Press.
Gilbert, J., Hipkins, R., & Cooper, G. (2005). Faction or fiction: Using narrative pedagogy in school science education. In *Redesigning Pedagogy: Research, Policy, Practice Conference* (pp. 1–16).
Glaser, M., Garsoffky, B., & Schwan, S. (2009). Narrative-based learning: Possible benefits and problems. *Communications*, *34*(4), 429–447. http://doi.org/10.1515/COMM.2009.026
Glesne, C. (2006). *Becoming Qualitative Researchers*.
Goffman, E. (1974). *Frame analysis: An essay on the organization of experience*. Cambridge MA: Harvard University Press.
Gould, S. J. (1991). *Bully for brontosaurus: reflections in natural history*. WW Norton & Company.
Groffman, P. M., Stylinski, C., Nisbet, M. C., Duarte, C. M., Jordan, R., Burgin, A., … Coloso, J. (2010). Restarting the conversation: challenges at the interface between ecology and society. *Frontiers in Ecology and the Environment*, *8*(6), 284–291. http://doi.org/10.1890/090160
Hardin, G. (1968). The Tragedy of the Commons. *Science*, *162*(December), 1243–1248. http://doi.org/10.1126/science.162.3859.1243
Hartz, J., & Chappell, R. (1997). *Worlds apart: How the distance between science and journalism threatens America's future.* Nashville, TN.
Hawking, S. (1988). *A brieft history of time: from the big bang to black holes*. New York, NY: Bantam.
Hinyard, L. J., & Kreuter, M. W. (2007). Using Narrative Communication as a Tool for Health Behavior Change: A Conceptual, Theoretical, and Empirical Overview. *Health Education & Behavior*, *34*(5), 777–792. http://doi.org/10.1177/1090198106291963
Hopkins, D. (2013). Learning about Climate: An Exploration of the Socialization of Climate Change. *Weather, Climate, and Society*, *5*(4), 381–393. http://doi.org/10.1175/WCAS-D-12-00055.1
Kawalkar, A., & Vijapurkar, J. (2011). Scaffolding Science Talk: The role of teachers' questions in the inquiry classroom. *International Journal of Science Education*, (August 2015), 1–24. http://doi.org/10.1080/09500693.2011.604684
Klassen, S. (2009). The Construction and Analysis of a Science Story: A Proposed Methodology. *Science & Education*, *18*(3–4), 401–423. http://doi.org/10.1007/s11191-008-9141-y
Klein, H., & Noe, R. (2006). Motivation to learn and course outcomes: The impact of delivery mode, learning goal orientation, and perceived barriers and enablers. *Personnel Psychology*, *59*(3), 665–702. http://doi.org/10.1111/j.1744-6570.2006.00050.x
Kreuter, M. W., Green, M. C., Cappella, J. N., Slater, M. D., Wise, M. E., Storey, D., … Woolley, S. (2007). Narrative communication in cancer prevention and control: a framework to guide research and application. *Annals of Behavioral Medicine*, *33*(3), 221–235. http://doi.org/10.1080/08836610701357922
Kubli, F. (2001). Can the theory of narratives help science teachers be better storytellers? In F. Bevilacqua, E. Giannetto, & M. Matthews (Eds.), *Science Education and Culture: The Contribution of History and Philosophy of Science* (pp. 179–184). Lake Como and Pavia:

Science and Business Media.
Kuh, G. D., Cruce, T. M., Shoup, R., Kinzie, J., & Gonyea, R. M. (2008). Unmasking the Effects of Student Engagement on First-Year College Grades and Persistence. *The Journal of Higher Education*, *79*(5), 540–563. http://doi.org/10.1353/jhe.0.0019
Lambert, E. C. (2001). College students' knowledge of human papillomavirus and effectiveness of a brief educational intervention. *The Journal of the American Board of Family Practice*, *14*(3), 178–183.
Lawrence, A. (2009). The first cuckoo in winter: Phenology, recording, credibility and meaning in Britain. *Global Environmental Change*, *19*(2), 173–179. http://doi.org/10.1016/j.gloenvcha.2009.01.006
Lawson, A. E., Alkhoury, S., Benford, R., Clark, B., & Falconer, K. A. (2000). Concept construction and intellectual development in college biology. *Journal of Research in Science Teaching*, *37*(9), 996–1018.
Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Westport, CT: Ablex Publishing Corporation.
Leopold, A. (1949). *A Sand County Almanac, and Sketches Here and There*. New York, NY: Oxford University Press.
Margulis, L. (1998). *Symbiotic planet: a new view of evolution*. Basic Books.
Maria, K., & Johnson, J. M. (1990). Correcting misconceptions: Effect of type of text. *National Reading Conference Yearbook*, *39*, 329–337.
May, M. L. (1979). Insect Thermoregulation. *Annual Review of Entomology*, *24*(1 14), 313–349.
McNett, G. (2016). Using Stories to Facilitate Learning. *College Teaching*, *64*(4), 184–193. http://doi.org/10.1080/87567555.2016.1189389
McNutt, M. (2013). Climate Change Impacts. *Science*, *341*(6145), 435. http://doi.org/10.1126/science.1243256
Memmott, J., Craze, P. G., Waser, N. M., & Price, M. V. (2007). Global warming and the disruption of plant-pollinator interactions. *Ecology Letters*, *10*(8), 710–717. http://doi.org/10.1111/j.1461-0248.2007.01061.x
Moffett, J. (1968). *Teaching the universe of discourse*. Boston: Houghton Mifflin.
Mutonyi, H. (2016). Stories, proverbs, and anecdotes as scaffolds for learning science concepts. *Journal of Research in Science Teaching*, *53*(6), 943–971. http://doi.org/10.1002/tea.21255
National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Croscutting Concepts, and Core Ideas*. National Academies Press. http://doi.org/10.17226/13165
Negrete, A. (2003). Fact via Fiction. Stories that communicate science. *The Pantaneto Forum*, (January 2005). http://doi.org/10.13140/RG.2.1.5110.1207
Nisbet, M. C., & Scheufele, D. A. (2009). What's next for science communication? Promising directions and lingering distractions. *American Journal of Botany*, *96*(10), 1767–1778. http://doi.org/10.3732/ajb.0900041
Norris, S. P., Guilbert, S. M., Smith, M. L., Hakimelahi, S., & Phillips, L. M. (2005). A theoretical framework for narrative explanation in science. *Science Education*, *89*(4), 535–563. http://doi.org/10.1002/sce.20063
Olson, R. (2015). *Houston, we have a narrative: why science needs story*. Chicago and Londo: University of Chicago Press.
Parmesan, C. (2006). Ecological and Evolutionary Responses to Recent Climate Change. *Annual Review of Ecology, Evolution, and Systematics*, *37*(1), 637–669.

http://doi.org/10.1146/annurev.ecolsys.37.091305.110100
Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, *421*(6918), 37–42. http://doi.org/10.1038/nature01286
Patrick, B. C., Hisley, J., & Kempler, T. (2000). "What's Everybody so Excited about?": The Effects of Teacher Enthusiasm on Student Intrinsic Motivation and Vitality. *The Journal of Experimental Education*, *68*(3), 217–236.
Phelan, J. (1996). *Narrative as Rhetoric: Technique, audiences, ethics, ideology*. Columbus, OH: Ohio State University Press.
Prins, R., Avraamidou, L., & Goedhart, M. (2017). Tell me a Story: the use of narrative as a learning tool for natural selection. *Educational Media International*, *54*(1), 20–33. http://doi.org/10.1080/09523987.2017.1324361
Pruneau, D., Gravel, H., Bourque, W., & Langis, J. (2003). Experimentation with a socio-constructivist process for climate change education. *Environmental Education Research*, *9*(4), 429–446. http://doi.org/10.1080/1350462032000126096
R Core Team. (2018). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.
Rushin, J. W., De Saix, J., Lumsden, A., Streubel, D. P., Summers, G., & Bernson, C. (1997). Graduate teaching assistant training: a basis for improvement of college biology teaching and faculty development. *The American Biology Teacher*, *59*(2), 86–90.
Sauermann, H., & Roach, M. (2012). Science PhD career preferences: Levels, changes, and advisor encouragement. *PLoS ONE*, *7*(5), 1–10. http://doi.org/10.1371/journal.pone.0036307
Schank, R. C., & Berman, T. R. (2002). The pervasive role of stories in knowledge and action. In M. C. Green, J. J. Strange, & T. C. Brock (Eds.), *Narrative impact: Social and congnitive foundations* (pp. 287–314). Mahwah, NJ: Lawrence Erlbaum Associates.
Schussler, E. E., Read, Q., Marbach-Ad, G., Miller, K., & Ferzli, M. (2015). Preparing biology graduate teaching assistants for their roles as instructors: An assessment of institutional approaches. *CBE Life Sciences Education*, *14*(3), 1–11. http://doi.org/10.1187/cbe-14-11-0196
Shen, C., & Tam, H. P. (2008). The paradoxical relationship between student achievement and self-perception: a cross-national analysis based on three waves of TIMSS data. *Educational Research and Evaluation*, *14*(1), 87–100. http://doi.org/10.1080/13803610801896653
Shepardson, D. P., Niyogi, D., Choi, S., & Charusombat, U. (2009). Seventh grade students' conceptions of global warming and climate change. *Environmental Education Research*, *15*(5), 549–570. http://doi.org/10.1080/13504620903114592
Sparks, T. H., & Yates, T. J. (1997). The effect of spring temperature on the appearance dates of British butterflies 1883-1993. *Ecography*, *20*(4), 368–374. http://doi.org/10.1111/j.1600-0587.1997.tb00381.x
Sundberg, M. D., Armstrong, J. E., & Wischusen, E. W. (2005). A reappraisal of the status of introductory biology laboratory education in U.S. colleges and universities. *The American Biology Teacher*, *67*(9), 525–529.
Tallis, R. (1995). *Newton's sleep: Two cultures and two kingdoms*. New York, NY: St. Martin's Press.
Taylor, B. M. (1982). Text structure and children's comprehension and memory for expository material. *Journal of Educational Psychology*, *74*(3), 323–340. http://doi.org/10.1037/0022-0663.74.3.323

Thoreau, H. D. (1982). *Great Short Works of Henry David Thoreau*. Harper Collins.

Thorndyke, P. W. (1977). Cognitive structures in comprehension and memory of narrative discourse. *Cognitive Psychology*, *9*(1), 77–110. http://doi.org/10.1016/0010-0285(77)90005-6

Todorov, T. (1977). *The Poetics of Prose*. New York, NY: Cornell University Press.

Toolan, M. (2001). *Narrative: A critical linguistic introduction*. London: Routledge.

Treise, D., & Weigold, M. F. (2002). Advancing Science Communication- A Survey of Science Communicators. *Science Communication*, *23*(3), 310–322.

van Haneghan, J., Barron, L., Young, M., Williams, S., Vye, N., & Bransford, J. (1992). The Jasper series: An experiment with new ways to enhance mathematical thinking. In D. F. Halpern (Ed.), *Enhancing thinking skills in the science and mathematics* (pp. 15–38). Hillsdale, NJ: Lawrence Erlbaum.

van Peer, W., & Chatman, S. (2001). Introduction. In *Perspectives on narrative perspective* (pp. 1–17). Albany, NY: State University of New York Press.

Visser, M. E., & Both, C. (2005). Shifts in phenology due to global climate change: the need for a yardstick. *Proceedings. Biological Sciences / The Royal Society*, *272*(1581), 2561–9. http://doi.org/10.1098/rspb.2005.3356

Vygotsky, L. S. (1978). *Mind in Society: The Development of Higher Psychological Processes*. (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds.). Cambridge Ma: Harvard University Press.

Walther, G. R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T. J. C., … Bairlein, F. (2002). Ecological responses to recent climate change. *Nature*, *416*(6879), 389–395. http://doi.org/10.1038/416389a

Weaver, C. A., & Kintsch, W. (1991). Expository Text. In *Handbook and Reading Research Vol. 2* (pp. 230–245).

Weingart, P., & Guenther, L. (2016). Science communication and the issue of trust. *Journal of Science Communication*, *15*(05), 1–11.

Wise, S. (2010). Climate change in the classroom: Patterns, motivation, and barriers to instruction. *Journal of Geoscience Education*, *58*(5), 397–309.

Zabrucky, K., & Ratner, H. H. (1992). Effects of Passage Type on Comprehension Monitoring and Recall in Good and Poor Readers. *Journal of Literacy Research*, *24*(3), 373–391. http://doi.org/10.1080/10862969209547782

Zhang, Q. (2014). Assessing the Effects of Instructor Enthusiasm on Classroom Engagement, Learning Goal Orientation, and Academic Self-Efficacy. *Communication Teacher*, *28*(1), 44–56. http://doi.org/10.1080/17404622.2013.839047

APPENDICES

Appendix A

<u>Fall GTA Survey</u>

Name:
Gender:
Ethnicity:
Department
Program:

1. Compared to other students in your college and/or department, how much do you feel you know about ecology and the environment in general?
    a. A lot
    b. A reasonable amount
    c. A little
    d. Almost nothing
    e. Nothing
    f. I don’t know

2. Compared to other students in your college and/or department, how much do you feel you know about climate change?
    a. A lot
    b. A reasonable amount
    c. A little
    d. Almost nothing
    e. Nothing
    f. I don’t know

3. Compared to other students in your college and/or department, how much do you feel you know about the interaction between plants and their pollinators?
    a. A lot
    b. A reasonable amount
    c. A little
    d. Almost nothing
    e. Nothing
    f. I don’t know

4. What’s one way that phenology could affect the owl food webs we just looked at?

5. What are some environmental cues that might impact the timing of biological events?

6. Describe a *predictable* biological event that’s important to where you come from.

Additional questions asked during post-survey:

7. How much did the PowerPoint presentation that I gave you increase your knowledge of climate change?
    a. A lot
    b. A reasonable amount

    c. A little
    d. Very little
    e. Not at all
    f. I don't know

8. How much did the PowerPoint presentation that I gave you increase your knowledge of phenology?
    g. A lot
    h. A reasonable amount
    i. A little
    j. Very little
    k. Not at all
    l. I don't know