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AN EVALUATION OF DIGITAL STORYTELLING AS A NOVEL APPROACH TO SCIENCE COMMUNICATION AND EDUCATION

by

Kelsey Robson

Dissertation

submitted in partial fulfillment

of the requirements for the degree of

Doctor of Arts in the Department of Biological Sciences

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Committee Approval

To the Graduate Faculty:

The members of the committee appointed to examine the dissertation of KELSEY ROBSON find it satisfactory and recommend that it be accepted.

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November 9, 2016

Kelsey Robson
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RE: regarding study number IRB-FY2017-61: Connecting With Science Through Digital Storytelling: The Undergraduate Classroom

Dear Ms. Robson:

I agree that this study qualifies as exempt from review under the following guideline: ategory 2: Anonymous educational tests, surveys, interviews, or observations. This letter is your approval, please, keep this document in a safe place.

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Sincerely,

Ralph Baergen, PhD, MPH, CIP
Human Subjects Chair

January 23, 2017

Kelsey Robson
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RE: regarding study number IRB-FY2017-96: Connecting With Science Through Digital Storytelling: The K-12 Classroom

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Sincerely,

Ralph Baergen, PhD, MPH, CIP
Human Subjects Chair

Dedication

To my parents. For financially and emotionally supporting my education.

(and for introducing me to pikas)

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Abstract

Science and society have prospered together through a mutually supportive relationship. However, this relationship breaks down when scientific findings conflict with beliefs and values, or raise ethical and political questions. A potential solution is improved communication through digital storytelling. This process combines a story script with visual and audio media; the end product is a short video. The synthesis of a storytelling approach with modern technology is powerful. Research suggests that stories are an intuitive form of communication, activate multiple regions of the brain, and elicit a strong emotional response. Other studies demonstrate the utility of video for reaching large audiences and sharing information online. Scientists can use digital stories to frame their work and link experience to evidence. The use of personal media and a self-narrated script will humanize scientists and build trust with the public.

Science classrooms are an ideal environment to practice digital storytelling in. Stories mitigate information overload, provide societal context, and make content personal. I developed and evaluated a biology teaching module that combines digital stories with data sets, publications, experiments, and assignments. Students reported that watching the digital stories increased their interest in ecological research, improved their understanding of the research process and datasets, and helped them relate to the featured scientist. These outcomes are comparable to other studies that used videos as an educational tool.

Additional benefits come from asking students to create and share digital stories. To demonstrate how the process of digital storytelling results in learning, I make connections to the theories of constructivism and constructionism. To encourage teachers to integrate digital storytelling, I show how the process aligns with science education standards. Overall, digital storytelling provides useful training in science communication; however, there may be barriers to implementation. To address this, I conducted four digital storytelling case studies, measuring student attitudes and collecting teacher feedback. I found that digital storytelling increased student interest in, and understanding of, course content, helped students connect classroom learning with everyday life, and built rapport between classmates. To overcome barriers, practitioners need to master the technology, and practice making a digital story, before engaging students.

Preface

Most children dream of being astronauts, or ballerinas, or firefighters when they grow up. I wanted to be a pika. I quickly realized it was biologically impossible; thus, I aspired to something out of Farley Mowat's *Never Cry Wolf*. I practiced my pika calls when we hiked in the Rockies, taped a colorful pika poster above my bed, and posed for photographs in perfect imitation of my favourite mammal. And while I didn't live out my life on a talus slope surrounded by pikas, I did come close: I studied pikas as a scientist.

The culmination of my Master's degree was a publication in a scientific journal titled, "Low genetic diversity, restricted dispersal, and elevation-specific patterns of population decline in American pikas in an atypical environment." It was an important moment—my first major contribution to the scientific literature. But it was also a moment that left me intensely dissatisfied. I tried to share my publication with family and friends, explaining that *this* is what had kept me busy for the past two years. My aunt wrote back: "Congratulations on the achievement. I didn't understand most of the article, but it all sounds very scientific."

To my audience of non-scientists, I was speaking a different language. A complete failure in communication. You see, as an undergraduate and graduate student, I had only been trained to read and write journal articles. After all, peer-reviewed publication is invaluable to the scientific community; it's an effective way to share knowledge. But it's not the best way to communicate with the public. Therefore, I applied myself to mastering an alternative: **digital storytelling**. I started by attending a workshop hosted by StoryCenter, the organization that founded the digital storytelling movement. There, I learned about the different stages of the digital storytelling process, and how to use new tools like media editing software. I walked away from the workshop with my first digital story—a short video about my Master's research and its connection to a personal struggle (https://www.youtube.com/watch?v=16-rq5X-Cs8). This digital story has been shared in numerous different settings and with a variety of audiences. It is the perfect complement to my scholarly publication, and ultimately, the ignition spark for three years of doctoral research. The dissertation that follows more fully explores the use of digital storytelling as a novel tool for communicating, teaching, and learning about science. My goal is to examine the process of digital storytelling and demonstrate its effectiveness. In doing so, I hope to convince readers that digital storytelling is a useful endeavour; one worth setting aside other priorities to engage with and practice.

Chapter I
Introduction

"Drama lurks in every test tube"
–The Science Service

The year is 1955. The vaulted ceiling of the Atlanta Municipal Auditorium is ringing with the sound of animated voices, and the seats below are crowded with scientists. Warren Weaver, president of the American Association for the Advancement of Science, steps on stage to deliver a speech and bring the annual meeting to a close. His words carry a warning:

> "It is hardly necessary to argue, these days, that science is essential to the public. It is becoming equally true, as the support of science moves more and more to state and national sources, that the public is essential to science. The lack of general comprehension of science is thus dangerous both to science and the public, these being interlocked aspects of the common danger that scientists will not be given the freedom, the understanding, and the support that are necessary for vigorous and imaginative development." (Weaver 1955, 1259)

Today, Weaver's speech is no less relevant. Advances in science and technology continue to have a profound influence on the quality of life and health of people around the world. Science and society have prospered together through a mutually supportive relationship; however, there have also been periods of turbulence. When scientific findings conflict with religious beliefs, core human values, and long-held views, or raise ethical and political questions, a considerable strain is placed on the relationship (National Academies of Sciences, Engineering, and Medicine 2017). One solution is more frequent, and more effective communication. The National Academies of Sciences, Engineering, and Medicine (2017, vii) charge scientists with the responsibility, "as citizens, to share the results of their work with the broader public so they can reap its benefits as expeditiously as possible." Similarly, The National Science Foundation (2017) requires all research proposals to address a "Broader Impacts" criterion and identify potential contributions to society (for example, professional development of K-12 science teachers, or presentation of results in formats useful to the public). While it is clear that dissemination constitutes a critical stage of the research process, there is no prescribed way to do it. The National Academies of Sciences, Engineering, and Medicine (2017, vii) recognize that scientists communicate for different reasons, that there are multiple audiences for information, and that societal contexts vary considerably; therefore, "communication approaches need to be adapted to reflect the circumstances that prevail." Compared to the year 1955, we are a culture of handheld devices and internet technology. Dissemination through traditional platforms such as scholarly journals and academic meetings remains important, but does not do enough to strengthen the relationship between science and society. Better science communication requires a more multifaceted approach, and a suite of different tools (Mea et al. 2016). One such tool, and the focus of this dissertation, is digital storytelling.

Digital storytelling is a form of technology-driven storytelling that enables "computer users to become creative storytellers through the traditional processes of selecting a topic, conducting some research, writing a script, and developing an interesting story" (Robin 2008, 222). The script is narrated and combined with images, photographs, video clips, sounds, and music to create a rich multimedia experience. I strongly recommend watching the following examples from the StoryCenter YouTube channel for a better understanding of what a digital story is:

1) "Useful" by Dr. Sudipto Bannerjee (https://www.youtube.com/watch?v=ku59094kZsg&list=PL2zMrq22Y2vn47f7ZggYB0p1YnoqQlQs)

2) “Running to Ozone” by Dr. Caroline Pari (https://www.youtube.com/watch?v=JyQlamFjy-Q&index=2&list=PL2zMrq22-Y2vn47f7ZggYB0p1YnoqQlQs)

The process of making a digital story will be described in more detail in subsequent chapters. For now, I want to focus on *why* digital storytelling deserves a place in the science communication toolbox. This explanation begins with a broader discussion of the evolutionary origins of story, and a closer look at how stories influence the brain.

Evolutionary Origins

As I progressed through my postsecondary education, from one biology course to the next, I experienced an ever increasing number of “aha” moments: a concept would suddenly become clear as I connected it to an idea from another class. It was the theory of evolution, more than anything else, that precipitated such insights. To quote the great Dobzhansky (1973, 125): “Nothing in biology makes sense except in the light of evolution.” This statement is relevant to human nature as well. In *On the Origin of Stories*, Boyd (2009, 13) argues that “we need to see human nature, like the rest of life, within the framework of evolution.” Just as behaviours like kin selection and parental care are best explained as adaptations—traits modified by natural selection that enhance fitness—so too is the behaviour of art (Boyd 2009). Boyd (2009, 73) supports his position with six observations: 1) art is universal; 2) art has persisted over time; 3) art takes the same major forms in all societies (music and dance, visual design, story and verse); 4) art is costly (time, energy, resources); 5) art elicits strong emotions; and 6) art develops in all normal humans. *On the Origin of Stories* validates each observation with compelling evidence, but for our purposes it is sufficient to summarize the main point: *If* all of these observations are true, *then* art must be an evolved, adaptive trait. An evolutionary psychologist would say that our connection to art is the result of natural selection for cognitive traits that increased survival and reproduction (Buss 2016). Similarly, Boyd (2009, 85) encourages us to view art as a kind of "cognitive play" that serves as a stimulus and training for a flexible, creative mind; the type of mind required to navigate a complex social world. Boyd (2009, 108) insists that there are major social benefits to art: "getting along (improved cooperation, and therefore participation in more successful groups)," and "getting ahead (improved status within one's own group)." In order to survive and reproduce, humans had to *cooperate* with conspecifics to earn resources obtainable only together, but also *compete* with conspecifics to maximize their share of those resources (Boyd 2009, 45). Art confers a selective advantage in highly social environments because it increases cognitive stimulation, social cohesion, and individual status. Boyd admits that the survival consequences of art may be "difficult to tabulate", but that ultimately, "they are profound" (Boyd 2009, 125).

Recognizing art as an adaptation is important here because stories, and storytelling, are a major form of art. From Rakugo, comic monologues told on Japanese stages (Harrigan 2017), to Cheriyal scrolls, scenes painted on canvas in the Telangana region of India (Mahesh 2015), stories are an important part of every human culture (Hsu 2008, 46). Anthropologists have found records of ancient folktales written in Sanskrit, Latin, Greek, Chinese, Egyptian, and Sumerian (Hsu 2008, 46). Oral storytelling features prominently in the history of groups like the Finns, who sing a national epic called the Kalevala (Finnish Literature Society 2017), the Manding people, who honor professional historians and musicians called Griots (Agatucci 2005), and the Maori, who have an institution called *whare wananga* that trains men to pass on tribal lore (Best 1934, 78). Recognizing this diversity of forms, we must diverge for a moment to a new question: “What *is* a story?”

Rayfield (1972, 1085) asserts that “there exists universally in the human mind the concept of a certain structure that we call a story,” and that this concept is a “natural psychological unit.” Although this definition fails to meet scholarly standards, searching for an alternative amongst the myriad interpretations, such as those discussed by Hsu (2008), Snowden (1999), and Stein (1982), tended too far in the other direction. That is, fields like narratology and pragmatics explore story in a deep, and often theoretical way; what we need is a simple, working definition. Thus, I turned to a more accessible source—The Oxford English Dictionary (3rd ed., s.v. “story”)—which defines story as “an oral or written narrative account of events that occurred or are believed to have occurred in the past.” Renowned novelist E.M. Forster (1927, 51) puts this in even simpler terms: a story is “a narrative of events arranged in a time sequence.” For our purposes, this concise definition is ideal.

In *The Storytelling Animal: How Stories Make Us Human*, Gottschall (2012, xiii-xiv) describes the human relationship with story as one that borders on obsession:

> Tens of thousands of years ago, when the human mind was young and our numbers were few, we were telling one another stories. And now, tens of thousands of years later, when our species teems across the globe, most of us still hew strongly to myths about the origins of things, and we still thrill to an astonishing multitude of fictions on pages, on stages, and on screens—murder stories, sex stories, war stories, conspiracy stories, true stories and false. We are, as a species, addicted to story. Even when the body goes to sleep, the mind stays up all night, telling itself stories.

Boyd (2009) believes the we are addicted to stories because of their ability to coordinate and secure attention—a variation on the social cohesion and individual status hypotheses. Boyd (2009, 393) points out that “attention to one another comes so naturally to us all that we rarely think about its biological significance." But a group that can share and synchronize attention is more likely to succeed with difficult tasks (Boyd 2009), such as hunting large prey animals, or defending against attacks. And within a group, an individual who can command attention is more likely to gain status, and better access to resources as a result (Boyd 2009, 393). From an evolutionary standpoint, the best storytellers, and the groups with the best stories, were the most likely to survive and reproduce. Boyd (2009, 399) adds that "the aim of securing attention can explain the design features of stories from jokes to children's pretend play to timeless masterpieces or avant-garde challenges." Fiction in particular, with its "rapid switches of place, time, and perspective must…speed up the capacity to guide and redirect social attention" (Boyd 2009, 191).

According to Hsu (2008, 46), fiction has another adaptive function: it is a "training ground" where we practice interacting with others and learn the rules of our group. Gazzaniga (2008, 224) provides a contemporary example: "From having read the fictional story about the boy who cried wolf when we were children, we can remember what happened to him in the story and not have to learn that lesson the hard way in real life." Fictional scenarios help us understand real dangers, and formulate plans to avoid them. Pinker (2007, 172) puts this in slightly different terms: He describes fiction as "a kind of thought experiment" in which characters act out plausible interactions, and audiences take note of the results. Fiction allows us to learn without subjecting ourselves to actual risk. So too, does play. Boyd (2009, 189) notes that children engage in pretend play—in the telling and acting out of fictional stories—spontaneously and without training. Gottschall (2012, 7) has memories of his own daughters caught up in a world of make-believe, like the

Darling children and their adventures through Neverland; he concludes that "story is so central to the lives of young children that it comes close to defining their existence."

Evolutionary thinkers argue that "if story were just pleasurable frippery, then evolution would have long ago eliminated it as a waste of energy" (Gottschall 2012, 30). But storytelling and story consumption persist *despite* the considerable investments of time, energy, and resources; thus, the benefits—cognitive stimulation, improved social cohesion and individual status, secured and coordinated attention, thought experiments—must outweigh the costs. These hypotheses are well-supported by research from the field of evolutionary psychology. The well-known works of Pinker (1997; 2013), and Cosmides and Tooby (Barkow, Cosmides, and Tooby 1992; 1997; 2005, 5-67), have advanced many similar ideas about the origins of story. However, these scholars also acknowledge competing hypotheses; for example, that our attraction to story is just a byproduct of other capacities (Bloom 2012, 390). Pinker (1997, 525) invokes a simple analogy to explain this particular hypothesis: "Many people love strawberry cheesecake, but this is not because our cheesecake loving ancestors out-reproduced their cheesecake shunning conspecifics. Rather, we possess certain adapted tastes, such as love of sweets, and cheesecake was invented to push these evolved buttons." Tooby and Cosmides (2001, 11) admit that there is a substantial body of evidence in favor of the byproduct hypothesis; however, the authors impress that "there is much that it leaves unexplained." Even today, scholars have not reached a consensus and the power of storytelling continues to intrigue. But considering the scope of this dissertation, I will leave it at this: Although the evolutionary origins of story can be explained by different hypotheses, its importance and universality are irrefutable. Storytelling is an intuitive and powerful form of communication; therefore, it is a useful skill for scientists to master. I have provided evidence for this argument from the field of evolutionary psychology, and will now draw upon a second source: neuroscience.

The Brain On Story

Humans encounter stories every single day, whether they are reading the newspaper, listening to an audiobook, browsing through a blog, or watching a movie. A defining similarity between these different modes is the richness of the experience. Zull (2002) explains that because stories engage all parts of the brain—activating memories, ideas, actions, and feelings—they allow us to package knowledge in complex neuronal networks. There is also a strong parallel between the sequence of events in a story and the physical connections that link neurons in the brain (Zull 2002). As Lodge (1990, 41) puts it: Stories are “one of the fundamental sense-making operations of the mind.” Discomfort with arbitrary events and disconnected facts drives our “hunger for narrative” (Brown, Roediger III, and McDaniel 2014, 109). Brown, Roediger III, and McDaniel (2014) describe an interesting study where readers were exposed to one or both sides of a background conversation. Results showed that the one-sided conversation was more distracting, presumably because the unintentional eavesdroppers were trying to infer the other side of the conversation (Brown, Roediger III, and McDaniel 2014, 110). Humans have a strong desire for coherence, and thus remain engaged with a story in order to find out what happens next.

Zull (2002, 62) explains that when we read a story, the executive centers in the front cortex produce imagined actions that give us pleasure. In other words, our brains enjoy a story because it goes somewhere, and because we experience it on a visceral level. A driving force behind this effect is language. González et al. (2006) used functional MRI imaging to examine the brains of test subjects as they read odor-related words—a type of descriptor used frequently in stories. Words like cinnamon, jasmine, and garlic activated the primary olfactory cortex, a region associated with our sense of smell (González et al. 2006, 907-908). In a similar study, Lacey, Stilla, and Sathian (2012) examined the brains of test subjects as they read sentences containing literary devices. Textual metaphors, like "she had a rough day," activated the somatosensory cortex, a region associated with our sense of touch (Lacey, Stilla, and Sathian 2012, 419). Lastly, Boulenger, Hauk, and Pulvermüller (2009) asked test subjects to read sentences containing verbs; specifically, arm-related or leg-related action words. Functional MRI scans showed activation of the brain's motor cortex, a region that coordinates movement (Boulenger, Hauk, and Pulvermüller 2009, 1910). What's more, the activation patterns were different depending on the body part referenced: stronger dorsal motor cortex activation for leg-related sentences, and stronger lateral cortex activation for arm-related sentences (Boulenger, Hauk, and Pulvermüller 2009, 1910). Paul (2012) neatly summarizes how the language of stories can affect us: "The brain, it seems, does not make much of a distinction between reading about an experience and encountering it in real life; in each case, the same neurological regions are stimulated."

Activating different parts of the brain is only the beginning: Stories can also influence behavior by changing brain chemistry (Future of StoryTelling 2012). Zak (2015) describes a study that measured participant's hormone levels after exposure to a dramatic story—a short video about a father struggling to connect with and enjoy his terminally-ill son. The story prompted the release of two primary hormones: cortisol, a hormone that focuses attention on something important; and oxytocin, a hormone associated with care, connection, and empathy (Zak 2015). After watching the video, participants were given the opportunity to share money with a stranger in the lab. Participants who had produced both cortisol and oxytocin were more likely to share the money generously; furthermore, the amount of oxytocin released predicted how much money people would share (Zak 2015). Hsu (2008, 46) explains that stories have a "unique power to persuade and motivate, because they appeal to our emotions and capacity for empathy." Karia (2014) adds that because you can share a message more implicitly through story, the audience doesn't feel preached to and is willing to listen. A study of over two hundred of the most popular TED talks concluded that story was the "magic ingredient" that made presentations captivating (Karia 2014, 2).

As individuals, we've all experienced the power of story (fighting with sleep to turn the pages of a good book; being reduced to tears in front of a big screen). What neuroscience contributes is a better understanding of what is happening biologically, and how groups, rather than just individuals, respond. This insight is particularly useful to scientists who are attempting to connect with a broad, public audience. The often quoted line "the plural of anecdote is not data" expresses the negative connotation story holds for some scientists (Dahlstrom 2014, 13614). While this is a legitimate concern about the validity of evidence, it is harmful in the context of communication. Dahlstrom (2014) provides a more helpful perspective: He references studies showing that nonexpert audiences are more attentive to and engaged with narratives, and mentally process them better than traditional logical-scientific communication (Dahlstrom 2014). Furthermore, most nonexperts already receive their information about science in a narrative form (Dahlstrom 2014). Meisel and Karlawish (2011) add that stories often win in the court of public opinion when matched strictly against data. The authors point to the example of celebrity Jenny McCarthy, who promoted the anti-vaccination movement with an emotional story about her child. McCarthy blamed the measles-mumps-rubella (MMR) vaccine for her son's autism, claiming "my son is my science" (Meisel and Karlawish 2011, 2022). What if we responded to this type of argument with both evidence *and* story? For example, the account of a mother whose infant, too young for the MMR vaccine, became sick and died after exposure to an unvaccinated child with measles. Meisel and Karlawish (2011, 2022) believe that such "counternarratives" can help the public make sense of population-based data: "Stories that link individuals and their experiences to evidence are tools to translate (not drive) science without introducing anecdotal bias."

I conclude that the evidence in favor of storytelling is robust and plentiful. To summarize: Stories are an excellent communication tool because they present information in a familiar way that is easy to process and package; stimulate multiple regions of the brain and provide an almost physical experience; elicit a strong emotional response; and link experience to evidence. Although these points focus primarily on how the audience is affected, scientists (by becoming storytellers), will enjoy some immediate benefits as well. For example, McDrury and Alterio (2003, 35) call storytelling "a way *to* knowing." Roger Schank (1990), one of the leading authorities on the power of narrative, asserts that storytelling is a key part of learning. His perspective is relevant to scientists, even though they are experts in their field of study. I believe that there is something to be learned, and much to be gained, from talking about science in a nontraditional manner. Renowned biologist Thomas Huxley (2003, 3) refers to this in his own unique way: “Some experience of popular lecturing has convinced me that the necessity of making things plain to uninstructed people was one of the very best means of clearing up the obscure corners of one’s own mind.” Although there is a touch of arrogance in what Huxley says, the phrase “making things plain” directs us to an important point: Storytelling can help scientists frame their work in an intelligible way. It is an exercise in thinking about how to present yourself, and the work that you do, in simple and relatable terms. The Center for Public Engagement with Science and Technology (2017) emphasizes how important it is to translate scientific information into a clear, three-point message, to avoid jargon, and to understand how the audience will respond. Stories meet this need: They have a defined beginning, middle, and end; use general and informal language; and appeal to the audience’s emotions. I will elaborate on these points in subsequent chapters. To round out this chapter, however, we need to transition to the modern age of technology. I have argued that storytelling belongs in the science communication toolbox, but have not yet addressed the digital component, or examined what the special attributes of a digital story bring to the table. These will be covered in the next two sections.

A New Communication Landscape

Using digital stories as their medium, the StoryCenter has “transformed the way that community activists, educators, health and human services agencies, business professionals, and artists think about the power of personal voice, in creating change” (StoryCenter 2017). A digital story has all the characteristics of a traditional story—plot, characters, setting, conflict, point of view, emotion, etc.—but combines and presents them in a unique way using technology. The main elements that differentiate a digital story are: 1) the equipment used to create the story; 2) the component materials; and 3) the method of dissemination (Table 1).

Table 1. Example comparison between a traditional and digital story

Type of story	Traditional	Digital
Equipment	Ink Paper Printing press	Camera Video recorder Scanner Microphone Computer Media editing software
Component materials	Words Drawings	Image files (e.g. JPEG, PNG) Audio files (e.g. MP3, WAV) Video files (e.g. MP4, MOV)
End product	Grimms' Fairy Tales	Short video about a scientist's background and research
Dissemination method	Printed text	Computer Internet

Simply put, digital storytelling is the modern reinvention of a traditional art; a process adapted to a society whose way of consuming, exchanging, and creating information has fundamentally changed because of computers and the Internet (Gannes 2009). A story in the form of a short video has several advantages, such as being ready for replay, or distribution to a mass audience, at the click of a button. Emanuel and Adams (2008) reported that college students spend 56% of their communication time engaged in receptive activities, such as watching and listening to media. Numerous educational studies have also shown that videos enhance learning (e.g. Hsin and Cigas 2013; Lloyd and Robertson 2012; Rackaway 2012), and can be particularly useful in the science classroom (e.g. Dash et al.

2016; Stockwell et al. 2015). Bell and Bull (2010, 1) describe contemporary uses of video as "casual and conversational;" a primary form of communication among today's youth. I think digital stories can help scientists engage a generation who have "spent their entire lives surrounded by and using…toys and tools of the digital age" (Prensky 2001, 1).

A unique advantage of a digital story is that, once made, it can be easily shared in many different contexts: an introduction to yourself at the start of a seminar; a way to appear more approachable to students on the first day of class; a feature on the lab website that explains your interests and motivations; a post on social media to increase your visibility with the public. With regards to this last context, we should acknowledge that there is value in "building buzz" about science through social media (Liang et al. 2014). Platforms such as Twitter and Facebook don't need to supplant more conventional forms of communication; however, they certainly can make an impact. Liang et al. (2014) surveyed top nanoscientists in the United States to explore the effects of communication behaviours on scientific impact. The authors reported that sharing publications on Twitter can actually assist a scientist's career, as "tweeted" work is cited more frequently by other scholars. Astrophysicist Neil deGrasse Tyson has taken full advantage of this new medium: he has a network of over seven million followers on Twitter with whom he shares information and samples of his authentic personality (https://twitter.com/neiltyson). Major scientific corporations, such as NASA and National Geographic, have also embraced social media. For example, dedicated Twitter followers receive invitations to go behind-the-scenes at NASA events, and the average post on the National Geographic Facebook page receives more than three thousand "likes" (Van Eperen and Marincola 2011, 2). Communication via social media happens rapidly, and can reach audiences in the millions.

Digital stories are perfectly adapted to this environment. Consider the flurry of online activity after a tsunami hit Japan on March 11, 2011: approximately 9000 earthquake related videos and 7000 tsunami related videos were uploaded to YouTube within twenty-four hours (Van Eperen and Marincola 2011, 3). The format of digital stories—short videos composed of visuals, movement, and sound—already matches how people consume and share information. We're simply putting a scientific spin on the content, and presenting a product that has been made with more thought and intention.

The March for Science is a recent movement that is using new communication channels to help scientists "reach out to their communities, sharing their research and its impact on people's everyday lives" (March for Science 2017b). The march organizers identify "education, communication, and ties of mutual respect between scientists and their communities" as a way to increase appreciation of science (March for Science 2017b). One of the satellite initiatives that the March has promoted is #ActualLivingScientist, a way for scientists to introduce themselves, and their incredible work, on social media. The online posts were initiated by wildlife ecologist and conservation biologist Dr. David Steen (Schumaker 2017). In its first two weeks, #ActualLivingScientist reached approximately 153 000 tweets on Twitter (hashtracking.com). Dr. Steen tweeted, "I'm Dave & an #ActualLivingScientist. I want to know how animals use & persist on landscapes so we can live alongside them at the same time" (Schumaker 2017). Accompanying this description are photographs of Dr. Steen outdoors, wearing casual field clothes, and holding *very* large snakes. A similar approach has been used on the March for Science Facebook page: members posted photographs under a byline to the effect of, "I am marching because ________" (March for Science 2017a). Reasons varied from the medical technology that saved a loved one's life, to supporting climate change education in schools, to the belief that science will ensure a better future for our children (March for Science 2017a). Some posts received dozens of replies and comments (March for Science 2017a), exemplifying a new type of interaction between scientists and non-scientists alike.

Bik and Goldstein (2013) have written an excellent guide to online dissemination resources, stating that "social media tools can be some of the most rewarding and informative resources for scientists—if you know how to use them." While social media may still be stigmatized by some scientists as a superfluous distraction, neglecting to communicate through the channels that the public uses means not being heard. As I have argued, digital storytelling can help address this challenge. Widely available equipment is harnessed to produce an online-friendly product—one that can be easily shared to new platforms such as Facebook and Twitter (for example, in place of a photograph accompanying a post or tweet). These "technical" aspects clearly differentiate digital stories from their traditional counterparts. But are there other distinguishing attributes? Ones that are particularly useful to scientists? The answer is yes; specifically, a self-narrated script and personal media. What follows is a brief discussion about how these qualities can help strengthen the mutually supportive relationship between science and society.

Building Trust

A digital story is a personal story. It reveals aspects of the author through a carefully crafted script, a voiceover thick with personality, and a collection of media such as old photographs and home videos. Conventions of formal academic writing, such as passive voice and inhibited emotional expression (Nature 2016), are turned on their head. For scientists, this means embracing a new style and presenting research and data in a way that emphasizes the human element. Although this approach may seem unconventional, and awkward at first, there is evidence to suggest that it can build trust. The business and management world is a particularly valuable source. For example, Offermann and Rosh (2012) report that "skillful self-disclosure" can humanize leaders, increase feelings of trust, and in an organizational context, promote collaboration towards mutual goals. Auvinen, Aaltio, and Blomqvist (2013, 505-506) label "personal disclosure" as an important dimension of manager trustworthiness. The authors reference practical examples, such as the pre-school principal who reportedly built trust with staff by "telling personal stories about my son's tree house and how the twins call me manager, although they know my name." Kraly (2017), who is the founder and CEO of a major corporation, revealed that "it was only when I started sharing little aspects of myself and tidbits from my life that I started seeing better sales and more engaged customers." In a similar way, telling personal stories in the classroom builds trust and understanding between the students and teacher (Buffo 2015; Green 2004; Lowenthal 2008; Wooten-Blanks 2012). For instance, Professor Wooten-Blanks (2012) reported student feedback after her self-disclosure that ranged from "I now realize you weren't given anything; you earned it all," to "You seem more approachable now." So, considering all the studies mentioned above, I think it is reasonable to infer that the personal aspects of a digital story will be useful in building trust between scientists and the public.

According to COMPASS, a National Science Foundation funded organization that trains scientists to communicate effectively, the key to public engagement is "finding common ground;" a "willingness to put not just your science out there, but also yourself" (McLeod 2017). Why is it so important for scientists to make this extra effort? The field of social psychology offers context for this question. Fiske and Dupree (2014) asked adults to rate the public image of different professions as warm/trustworthy, as well as competent/capable. The ratings were subject to a statistical cluster analysis that produced a map with four profession groups: high-warmth and high-competence; high-warmth and low-competence; low-warmth and high-competence; low-warmth and low-competence (Fiske and Dupree 2014, 13595, fig. 2). Can you guess which cluster the scientists and researchers fell into? Low-warmth and high-competence: professionals regarded with a mixture of respect, resentment, admiration, and distrust (Fiske and Dupree 2014, 13595, fig. 2). This lack of trust, in particular, is a significant problem for science communicators. Decades of research on public attitudes has resolved that trust is one of two main factors that establish the credibility of a communicator; the other is expertise (Fiske and Dupree 2014). So, what can competent, expert scientists do to build trust with an audience?

Connect through a digital story. Present a shared identity: People trust others who they recognize as being in their own group (Hogg 2010). Shinske et al. (2016) showed that this sense of identity is powerful enough to affect students' performance in an introductory biology course. The authors evaluated a series of homework assignments, called "Scientist Spotlights," that featured the stories of diverse scientists (Shinske et al. 2016). An example is summarized below:

> Ben Barres is a Stanford professor of neurobiology. He studies diseases related to signaling in the nervous system, and in particular the roles of supporting cells around neurons. Dr. Barres is also a leader in science equity and the effort to address gender gaps. He is uniquely positioned to address these issues, since he has presented both as a female and a male scientist at different times in his career.

> 1. View the *Wall Street Journal* article about Ben Barres...
> 2. Review Dr. Barres' article in the journal *Nature*…
>
> After reviewing these resources, write a 350 word or more reflection. (Shinske et al. 2016, 3)

One question that students were encouraged to address in their reflection was: "What do these articles tell you about the types of people that do science?" (Shinske et al. 2016, 3). Chambers' (1983, 258) notorious Draw-a-Scientist Test identified seven specific attributes that children associate with scientists: lab coat, eyeglasses, facial hair, symbols of research (such as laboratory equipment), symbols of knowledge (such as books), technology, and relevant captions (such as "eureka"). In addition, over 99% of the drawings that Chambers (1983) analyzed were of male scientists. Shinske et al. (2016, 2) argue that when stereotypes of scientists are so different from students' perceptions of themselves, students conclude that they are not "science people". At the beginning of the Scientist Spotlights intervention, one student remarked that her image of scientists was movie characters that were "geeky, had glasses, spoke monotone, and thought they were above everyone;" however, after completing the homework assignments her notion changed to, "Scientists are just normal people like myself. They love to learn new things, they have a life outside the laboratory, they are fun" (Shinske et al. 2016, 7). While this student's perspective is somewhat simplistic, it alludes to an important point: scientist stereotypes can be a barrier to trust. In reality, scientists are a diverse and colorful group. They face challenges such as inequality, poverty, and marginalization—the same types of challenges that "nonscientists" face. The majority (79%) of students who participated in the Scientist Spotlights homework found scientists relatable at the end of the course; this connection was attributed to "shared personalities," "interests outside science," and "nontraditional paths to gaining an interest in science" (Shinske et al. 2016, 13). Students in a control group were not impacted the same way: only 43% found scientists more relatable at the end of the course (Shinske et al. 2016, 13). What's more, the final course grades for students who completed the Scientist Spotlights homework were more than half a letter grade higher than the control group (Shinske et al. 2016, 15, fig. 5). If there is a such a positive response to teaching science content by connecting it to personal stories, why not approach other methods of science communication the same way?

A digital story that "humanizes" science doesn't have to focus exclusively on a scientist's background and beliefs; it can also explain the process of scientific research and discovery. For example: "We started with what we knew, we looked at the evidence, we revisited our hypotheses, we argued about the findings, and ultimately we acted here and now because it was prudent, but there are more data to come, and here is what we plan to do as we learn more" (Meisel and Karlawish 2011, 2023). Meisel and Karlawish (2011) believe that this type of disclosure can increase trust, and thus improve the acceptance of scientific evidence for individual use and public policy. As Fischhoff and Scheufele (2013, 14031) point out, "Science requires the public's support. Whether it is forthcoming depends on how much the public trusts and values science. Is the research worth the investment? Does it produce the jobs and health that it promises? Do scientists put the public's welfare above their interests?" Priest, Bonfadelli, and Rusanen (2003) illustrate how trust can influence people's opinions about science. The authors collected survey data from Europe and the United States, exploring perceptions of biotechnology, and asking which individuals and institutions in the industry were trusted. Priest, Bonfadelli, and Rusanen (2003, 765) determined that the variation in survey responses could not be explained by a knowledge gap: participants with more scientific knowledge didn't necessarily support biotechnology, and vice versa. Instead, the data support a "trust gap": public opinion on biotechnology is a reflection of the varying degrees of trust in different individuals and institutions (Priest, Bonfadelli, and Rusanen 2003, 760). A take-away message for scientists then, is to prioritize communication strategies that promote trust. The Center for Public Engagement with Science and Technology (2017) is already on board: They recommend a goal-oriented model for science communication, with a short-term outcome of humanizing scientists, and a long-term outcome of building trust with the public.

A lack of trust between science and society has serious consequences. The famous Isaac Asimov called public understanding of science "essential to preventing public hostility toward, and suspicion of, scientists and their works" (Gregory and Miller 1998, 10). The "climategate" scandal, resulting from the unauthorized release of email correspondence between climate scientists in the United States and England, is a cautionary tale. Leiserowitz et al. (2012) quantified the impact of climategate on Americans by conducting a nationally representative survey approximately one month after the scandal was publicized. The survey contained a series of questions that were completed by respondents who had heard of the climategate scandal. When asked, "Have these stories about the controversial emails caused you to have more or less trust in climate scientists?" over half of the respondents answered "much less" or "somewhat less" trust in scientists (Leiserowitz et al. 2012, 825). The survey also elicited opinions on the details of the scandal: 69% said they somewhat or strongly agreed with the statement, "Scientists changed their results to make global warming appear worse than it is"; 66% said they somewhat or strongly agreed with the statement, "Scientists conspired to suppress global warming research they disagreed with" (Leiserowitz et al. 2012, 825). The fabrication and falsification of scientific data are serious acts of misconduct that should not be withheld from scrutiny. However, if models of scholarly conduct and ethical behavior don't present themselves for comparison (for example, through a digital story), the public may harbor a biased and negative view of the scientific community.

The National Academies of Sciences, Engineering, and Medicine (2017, 14) define good science communication as "the exchange of information and viewpoints about science to achieve a goal." The key word in that sentence is *exchange*. A mutually supportive relationship between science and society requires trust, and an open, two-way dialogue. Varner (2014) critiques models of science outreach that portray the public as a homogenous, inadequately informed group, and assume a unidirectional flow of information from scientists to the public. Instead, the National Academies of Sciences, Engineering, and Medicine (2017, 25) use the phrases "mutual teaching and learning," and "public engagement," to describe new strategies for science communication. Under this model, the public not only listens, but also evaluates evidence, asks questions, contributes information, and offers unique perspectives. They act very much like confident employees working for a trustworthy manager, or inquisitive students talking to a respected professor. However, these constructive environments do not develop overnight. We can defer to the old saying, "You get out what you put in." Achakulwisut (2017) implores that we change the mantra of academia from "Publish. Publish. Publish," to "Publish. Communicate. Engage." I strongly agree.

Training and Practice

To build a better relationship between science and society, scientists need to commit to both training and practice in new communication techniques. From their experience with postsecondary students, Brownell, Price, and Steinman (2013, E7) observed that, "Developing skills to communicate science at a level that a general audience can understand requires deliberate practice and careful attention to language." The authors described a neuroimmunology course in which they integrated formal training in communication, but remained focused on scientific content. Students were required to write New York Times Science Tuesday-style articles every two weeks, summarizing key aspects of scientific papers. Although their emphasis was on the written word, Brownell, Price, and Steinman (2013) encourage diversity in the ways that students prepare to communicate with the public. Other scientists are on the same page. Case in point, graduate students and researchers from the University of Texas at Austin developed and evaluated two unique programs that combine training in science communication with outreach to middle schools: "Present Your PhD Thesis to a 12-Year-Old," and "Shadow a Scientist" (Clark et al. 2016, 2). The results were overwhelming positive: Students' knowledge and enthusiasm for science increased; scientists' ability to explain their research to a general audience improved and they gained a "new perspective" (Clark et al. 2016, 4-5). Although the scientists had to invest a substantial amount of time in the programs, there was a high payoff. Berkeley Ph.D. student Sara ElShafie knows this better than most (Dong 2017). She balances her dissertation research with science communication workshops. Collaborating with artists at Pixar Animation Studios, ElShafie adapts storytelling strategies from the film industry to science communication. She leads workshops for scientists, helping participants develop a "conceptual framework for introducing scientific topics in the form of a story" (Dong 2017). Her audiences have grown threefold, to attendances of nearly 200 at recent workshops (Dong 2017). ElShafie reports that "story training benefits scientists, because it helps us to communicate [science] in a clear and compelling way to any audience" (Dong 2017).

Clearly, there are motivated organizations and individuals who are moving in the direction of "Publish. Communicate. Engage." Unfortunately, this trend is far from universal. Therefore, my aim is to convince more scientists to reach out to the public and employ novel communication tools. I have used evidence to argue that storytelling be included in these efforts because it is an intuitive and powerful form of communication; I have used evidence to argue that *digital* storytelling be included because it is adapted to an online landscape and helps build trust. However, I have not yet examined the practical applications of digital storytelling, nor provided much direction on where or how to get started. The next two chapters will thus evaluate the integration of digital storytelling in different science education settings; the final chapter will unveil a recipe for making quality digital stories.

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Chapter II
Teaching with Digital Stories

"As all of us in our singularly social species know, there are few ways of holding others longer than by telling a vivid story."
–Brian Boyd

Where should digital stories be told? Well, in the Introduction I mention several different contexts, such as a seminar, lab website, or social media page. Here, I'd like to focus on an environment that is ideal for *practicing* digital storytelling: the classroom. Academic scientists have access through regular teaching duties, and are given the autonomy to design courses and integrate new tools. What's more, students provide a large sample size from which it is relatively easy to obtain feedback. After considering these advantages, I decided to create and test a teaching module that incorporates digital stories. This type of investigation is conventional to the scholarship of teaching and learning, or "published work on teaching and learning authored by college faculty in fields other than education" (Weimer 2006, 19).

In the Practice section of this chapter I will describe the design and implementation of the teaching module, and examine its impact on student attitudes and overall effectiveness as a teaching tool. To start, however, I need to build upon arguments made in the Introduction. The Theory section will thus review additional literature on the role of storytelling in education, and discuss how stories have been used to teach science. My aim for this chapter is to convince scientists to incorporate more storytelling into classroom teaching; either by creating and sharing personal digital stories, or using the digital story-based module I created.

Into the Classroom

The United Nations Educational, Scientific and Cultural Organization (2010) considers storytelling a key teaching and learning strategy. Others agree. The application of storytelling to educational settings is supported by numerous studies. For instance: Daneshyar (2012) describes how stories transform economics lectures from an atmosphere of apathy and passivity to absolute focus; Vitali (2016) shows how storytelling projects help preservice teachers engage students cognitively, culturally, and linguistically; and Sorrell (2001) claims that sharing stories builds community and trust in nursing education programs. What's more, there are now dozens of online and printed resources to assist teachers in their own storytelling endeavors. Three exemplars are Sheppard's website (http://www.timsheppard.co.uk/story/index.html), Egan's *Teaching as Story Telling: An Alternative Approach to Teaching and Curriculum in the Elementary School*, and McDrury and Alterio's *Learning Through Storytelling in Higher Education*. McDrury and Alterio (2003, 37) encourage teachers to tell stories to "introduce new material in entertaining and interesting ways, to share practice experiences which demonstrate key teaching points, and to reveal aspects of ourselves." Green (2004) also advocates for the use of stories in the classroom, but for slightly different reasons: 1) stories make content interesting to students through emotion and characters; and 2) the structure of a story provides connections between concepts and a cue for recall (Green 2004). Green (2004) elaborates on this second point: "Because stories provide natural connections between events and concepts, mentioning one part of the story may help evoke the other parts of the story, just as hearing one bar of a familiar tune may bring the entire song to mind." Whether it is a cue for recall, an attention grabber, or an emotional connection, storytelling clearly has the potential to improve teaching and learning.

Schank (1990, 15) proclaims: “A good teacher is not one who explains things correctly but one who couches explanations in a memorable (i.e., an interesting) format.” Put another way, a good teacher isn’t just a content expert, but an adept storyteller as well. Daneshyar (2012, 1) agrees: He believes that personal anecdotes are a particularly effective way to teach course content because they evoke students’ emotions, providing a “visceral connection vital to the long term retention of the subject matter in their memory banks.” With that in mind, consider the following scenario:

Amy slumps in the back row of her biology class. She watches the minutes slide by, eyes wandering back and forth between the clock and her notes. But then something unexpected happens. Her professor starts to tell a story. It’s about wading through a forest in the middle of a downpour, stumbling along the edge of a river in search of a platypus. But the day is drawing to an end. A chill settles in and the sodden rain jacket is a miserable weight. The professor trudges back to her cabin. She pushes open the door and stands for a moment in the entrance. Her husband looks up from his spot on the couch and screams. That’s when the professor notices her feet—two masses of leeches at the bottom of her legs. The sandal straps are barely visible. Back in the river, the leeches found the professor’s feet using their body hair and simple eyes: The hairs sensed waves created by the passing limb, and the eyes tracked the shadows created by the waves. Then, using their three jaws, the leeches cut through the human skin. The professor didn’t notice because of salivary secretions: A special blend of hirudin, to prevent clots and maintain blood flow, and anesthesia, to prevent pain and a reaction to the attack. The professor sits down, resigned. Her husband brings over the table salt and they apply it to the leeches with purpose. Thirty minutes later, the professor is through the ordeal. Amy finally looks up at the clock. Class dismissed.

The professor’s account brings substance to an otherwise nondescript set of facts about the biology of a parasite. The story contains key elements that Szurmak and Joanna (2013, 549) show will engage the brain in learning: Emotion, strong events and problems, a practical context, and detail within an overarching structure. It is exactly the type of story that earns the attention of an entire lecture hall; I know because I was listening from a seat just behind

"Amy." Recognizing this focus as a desired outcome, is there a prescribed way to emulate the professor's performance?

If we want to capture and hold students' attention, the stories we tell must meet a certain standard. Stein (1982, 18) cautions that "the needs, preferences, and beliefs of a comprehender enter into our judgments of goodness in determining story ratings." In other words, a story may resonate with one student, but not the next. So how do we ensure that a story engages, at the very least, *most* of the students in a class? My answer is proper story structure. According to Rayfield (1972, 1101), this is something that we already have an "intuitive sense" for. It is no coincidence that anthropologist Joseph Campbell (1956, 30) identified a single, common structure underlying storytelling around the world: a "monomyth" with three major parts—beginning, middle, and end. Olson (2015, 35) describes an apt metaphor for the monomyth:

> "There are so many seemingly different types of stories—romance, horror, comedy, fantasy and more. If you choose to do so you can get lost in the infinite complexity of them. Similarly, you can get lost in the infinite complexity of biological diversity…each creature is so different from the next….And yet…at the core, their DNA is telling the same story. Their genomes track back to the same original primal sequences of base pairs….It's the same with stories."

In the historic work *Poetics* (c. 335 BCE), Aristotle separates the basic structure of stories and plays into three parts: an opening—*prologue*, a middle with repeating cycles of *parados, episode,* and *stasimon*, and an ending—*exodus* (Olson 2015, 33-34). We are implicitly familiar with this three act structure; it is the foundation of most stories that play out on the stage and screen. Gustav Freytag, a nineteenth century novelist, expanded this tripartite to the five stages of exposition, rising action, climax, falling action, and denouement (*Merriam Webster's Encyclopedia of Literature* 1995, "Freytag's Pyramid").

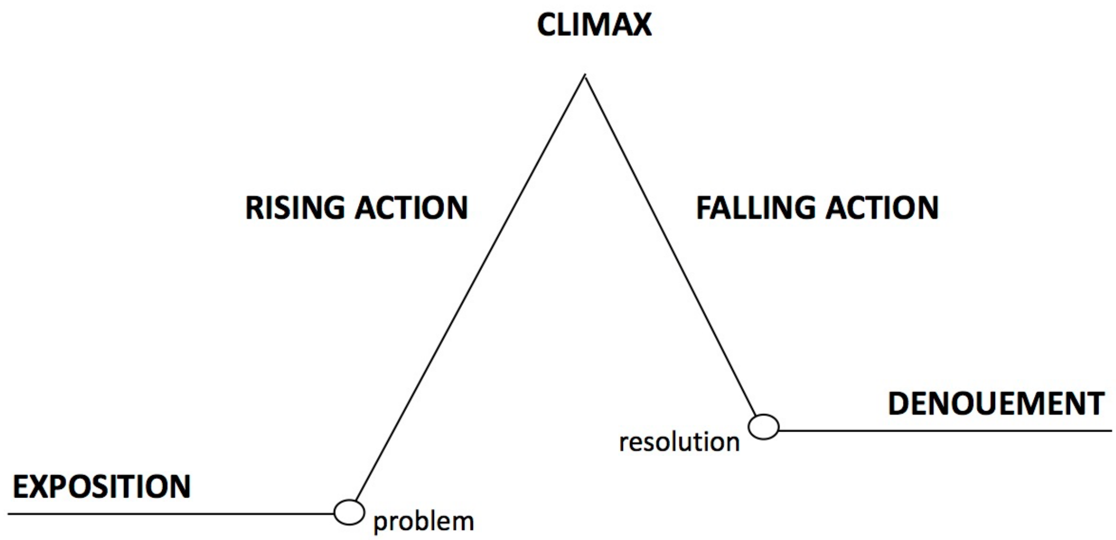

Figure 2. 1. The five stages of Freytag's Pyramid. Adapted from Mou and Chen 2013, Figure 3.

Freytag's pyramid is a simple framework that can help educators identify and create engaging stories (Figure 2.1). Remember the story about the father and his terminally ill son, from Zak's (2015) study of brain chemistry? It was modeled after Freytag's pyramid, and evoked such a strong sense of empathy that it inspired prosocial behavior. In contrast, the control story about the same father and son walking through a zoo had no measurable effect (Zak 2015). The control story was a straight line; it lacked the structure of Freytag's pyramid. As a result, the audience disengaged. Zak's (2015) study reinforces the fact that not all stories are created equal. My advice to educators using storytelling for the first time: Go back to the classroom and share personal narratives with your students; distribute historical accounts of famous scientists; orate Native American tales about ecological relationships. *But do so critically*. Look for and model Freytag's pyramid. Note the reactions of your students and solicit feedback. Daneshyar (2012, 10) emphasizes that storytelling is an "acquired skill." He has published detailed guidelines for developing the talent (Daneshyar 2012, 10-11), but here they are in brief: 1) Practice storytelling in front of your class; 2) Be spontaneous in your delivery; 3) Adapt your stories to the audience; 4) Expand your story repertoire; and 5) Plumb personal experiences for educational value. Over time, through careful consideration and experimentation, you can build a portfolio of well-structured stories for the classroom. Kieran Egan (1989, 459), an authority on storytelling in education, offers this final perspective:

> "Thinking of teaching as storytelling also encourages us to think of the curriculum as a collection of the great stories of our culture. If we begin to think in these terms, instead of seeing the curriculum as a huge mass of material to be conveyed to students, we can begin to think of teachers in our society as connected with an ancient and honored role. Teachers are the tellers of our culture's tales."

Teaching Science

Storytelling has a definite niche in the humanities, but what about the sciences? Although we're inclined to associate numbers and facts with subjects like organic chemistry and molecular biology, Olson (2015, vii) reminds us that "Science is permeated with story. Both the scientific method and the communication of science are narrative processes." In fact, a typical research project bears an uncanny resemblance to Aristotle's three-part story structure: You start by gathering background information (*prologue)*, repeat cycles of posing, testing, and rejecting/failing to reject hypotheses (*parados, episode,* and *stasimon*), and then formulate a conclusion (*exodus*) (Olson 2015, 33-34). If story is already an integral part of doing science, it merits a role in the teaching of science. For example, Green (2004) describes how difficult it is for students to remember the isolated concepts and definitions encountered in, say, an introductory physics course; however, "recalling the flow of a research story may be easier." Similarly, Herreid (2007, xiv) contends that "stories put learning into context," while traditional lectures are "abstract with mountains of facts." Fien et al. (2010) even developed a storytelling module for teachers to reinforce that "a good story is not only entertaining but is capable of holding student attention while they learn important concepts." Storytelling, therefore, offers a way to mitigate the information overload and jargon associated with science courses. But that is only one of many possibilities.

A well-established way to combine science and story is through case study teaching. In *Start with a Story: The Case Study Method of Teaching College Science,* Herreid (2007) instructs readers how to teach with cases in different classroom settings. He defines case studies as "stories with an educational message," and praises the approach for providing real life context for learning (Herreid 2007, xiv). An excellent example is Hutchison's (2007) case study about disputed maternity. Written for an introductory biology course, the case incorporates concepts from genetics, inheritance, and the formation of pedigrees. The first thing the students read is an immediate attention grabber and an appeal to human emotion: "You know, Karen, something very unusual has happened here. We've tested your sons because they were possible donors. Your sons' blood does not match your blood and that's an impossibility, so they couldn't be your children…these could not be your children" (Hutchison 2007, 25). As students work through the case, they are required to propose and evaluate different hypotheses. The results of lab reports and tests are progressively disclosed, just like any good medical drama on television, and the science is embedded in a societal context, with moral and ethical implications to consider. The students learn genetics as problem solvers instead of note takers. An unpublished review commissioned by the National Center for Case Study Teaching in Science reported that 97%

of students taught with cases learned new ways to think about an issue, and 95% took a more active role in the learning process (Herreid 2005).

Stories about scientists themselves can also inspire learning (Ahn et al. 2016; Eshach 2009; Lin-Siegler et al. 2016; McKinney and Michalovic 2004). Klassen and Klassen (2014, 1503) advocate for the use of historically-based stories in science education, as they increase interest and motivation by "presenting humanistic episodes that explicitly include scientific content." One example is the *Darwin* exhibit at the American Museum of Natural History. The storyline of the exhibit is that Darwin was only human: someone enchanted by the patterns of the natural world, and something of a workaholic, but also a devoted family man and father of ten children (Eldredge 2009). While *On the Origin of Species* is arguably one of the most influential scientific works, its author is not an eccentric savant; rather, "a man of passion who, being in the right places at the right times, managed to see farther than his predecessors and contemporaries had" (Eldredge 2009). Exhibit curator Niles Eldredge (2009) believes *Darwin* shows people that "science is really not all that different a category of creative human endeavor than, say, writing a beautiful haiku." The curator of the Alexander Fleming Laboratory Museum in London would probably agree. Avraamidou and Osborne (2008) describe the museum as a three-room building that transports audiences from the restored laboratory where Fleming used to work, to an audiovisual chamber, to a display room with poster boards. The story of the discovery of penicillin is interwoven with biographical information; Fleming is the protagonist facing surprises and setbacks. Both museums are exemplars of how to use story to explain science and illustrate its cultural significance.

Disciplines such as chemistry, biology, and physics are often described as impersonal and objective: “We seldom hear of the passion, emotion, or personal matters of a Newton, Einstein, Lavoisier, Lyell, or Pasteur…so, many students sit in class waiting for the suffering to be over, or they change majors to other more human-centered fields where the subjective, the individual, matters” (Herreid 2007, 22). But it is not just the famous scientists whose stories need to be told. Herreid (2007, 21) asks: “Where are the stargazers, the lab workers, the diggers of fossils in our classroom lectures? A Charles Darwin or Richard Feynman gets a pat on the head, but the rest of our artwork is unsigned.” So pick up a pen. Portraying science as your “intellectual adventure” (Eldredge 2009), or “quest for knowledge” (Green 2004), automatically makes the subject matter more inviting. Scerri (2017), a leading researcher on the history and philosophy of chemistry, points out that famous, award-winning scientists certainly do their part to advance knowledge; ultimately though, it is the everyday, unwavering, and incredible effort of the whole that drives scientific progress.

To summarize the Theory section: Evidence shows that storytelling is an effective teaching tool with relevance to science education; more specifically, stories help manage information overload, provide societal context, and make content personal. Acknowledging these benefits, I decided to create and test a teaching module that uses digital stories in a novel way; specifically, in support of large data sets, journal articles, experiments, and student assignments. I measured student attitudes towards digital storytelling, and tested video content recall in a college classroom. The module is appropriate for undergraduate or high school students, and covers topics from biology, ecology, and entomology. A lab space, classroom, and access to computers are required.

Introduction

The Digital Rocky Mountain Biological Laboratory (RMBL) website brings long-term studies of natural systems into college classrooms, advancing the following goals: 1) present research in a manner that is accessible, inviting, and compelling to students; 2) improve students' scientific process skills; and 3) provide training in the use of online data resources (Ellwein et al. 2014, 579). Digital RMBL hosts teaching modules which were developed by a committee of scientists, and then evaluated in college classrooms. The *Biology of Climate Change* module received the most attention; it was tested by 10 collaborating faculty and 243 undergraduate students at multiple institutions (Ellwein et al. 2014, 583-584). A primary strength of the module was the fascinating character of billy barr, a citizen scientist who lives a reclusive life in the mountains of Colorado (Ellwein et al. 2014, 581). In the summer he holds an administrative position at RMBL; in the winter he fills notebooks with snowpack measurements and field observations. The forty-four years of data that billy has collected are an invaluable resource for climate scientists (Phippen 2017). According to Ellwein et al. (2014, 581), "[billy's] story is a particularly interesting 'hook' for many students." Indeed, it was picked up by multiple magazines and news agencies, from *National Geographic*, to the *Daily Mail*, to *Outside*. Although the story of "the snow guardian" is certainly an exceptional example (Day's Edge Productions 2016), the biographies of more typical scientists also hold surprises and delights.

Building on the attention to billy barr, and capitalizing on my knowledge of digital storytelling, I created a new teaching module for Digital RMBL that has a rich story component. *Tiny Grave Diggers: Exploring the Ecological Role of Burying Beetles* uses photographs, short video clips, and digital stories to provide context for student assignments and data sets. From this larger collection of media, the digital stories are the main attraction. Lindgren and McDaniel (2012) also developed learning modules supported by video recorded multimedia presentations, and found that student learning and engagement increased as a result. In a related study, Baim (2015, 48) reported that short instructional videos based on the best practices of digital storytelling "provide direct knowledge, stimulate course discussion on key topics, and encourage learners to pursue further study." I expect my digital stories to have a similar effect on students as what was reported by Lindgren and McDaniel (2012), and Baim (2015). However, for evaluation purposes I generated more specific goals. The digital stories will: 1) Increase student interest in burying beetles and ecological research; 2) Help students understand the research process and the large data sets; and 3) Present scientists in a relatable way. A survey was administered to assess these three goals, and a quiz used to measure information recall.

An important theme of the module is the depiction of RMBL as not just a place of research, but also a place of community. This emphasizes the idea that science is a human endeavor. Indeed, a key part of RMBL's success as a center for scientific research are the opportunities for collaboration, mentorship, and friendship. While most students won't experience this for themselves (bringing a class to the field station is financially and logistically challenging), the digital stories and other contextual elements serve as a substitute for an in-person visit. For example, the video titled "A Day in the Life" follows a field assistant through a typical day at the research station, and a photograph of a researcher climbing a peak above RMBL with her wedding party portrays the community atmosphere. Because this media is published on the Digital RMBL website, and can be accessed be a large, remote audience, I hope it will help connect the broader public with the human faces behind scientific research.

Module Components

The components are hosted on the Digital RMBL website, as part of the *Tiny Grave Diggers* module (see http://www.digitalrmbl.org).

Student Assignments

The primary way in which students interact with the module is through three student assignments. In many ways the assignments act as a map, directing students to specific learning materials, and in a particular order, so that they can solve problems and answer questions. The assignments provide practice in the Seven Segments of Scientific Inquiry, with particular emphasis on five to seven: 1) exploring a phenomenon; 2) focusing on a question; 3) planning the investigation; 4) conducting the investigation; 5) analyzing the data and evidence; 6) constructing new knowledge; and 7) communicating new knowledge (Llewellyn 2013, 7). Students are exposed to different stages of the research process, such as reading primary literature, proposing hypotheses, conducting experiments, and analyzing data. The three assignments are listed under the file names "Species-habitat interactions," "Population dynamics," and "Energy transfer."

Contextual Elements

There are three categories of contextual elements (Table 2.1): photographs (see Appendix A), video clips, and digital stories. Photos and video footage were taken on-site at RMBL during July 2015 and 2016; a Pentax Q-S1 digital camera and Canon Vixia HF

G20 camcorder were used. Photo editing was completed in Adobe Photoshop, while QuickTime and Adobe Premiere Pro were required for video editing. The digital stories were made using the recipe which will be presented in Chapter IV. Voiceovers were recorded with a Samson Meteor Microphone and edited in Adobe Audition. Other sounds and music were legally obtained from online sources. The digital stories were produced in Adobe Premiere Pro.

Table 2.1. Contextual elements

Folder names	File names
Photographs	Confrontation RMBL Levi Alpine Wedding Gravediggers
Video clips	Google Earth tour How to sex a beetle
Digital stories	Welcome to RMBL A day in the life The beetles are calling… What does the beetle say? The story behind the data The story continues

Learning Materials

A combination of data sets, experiments, publications, and images are tied to the student assignments (Table 2.2). There are six data sets: beetle census, rodent census, climate data, Schnabel method, population index, and beetle biomass. The beetle census and rodent census are Excel files of sampling data contributed by Dr. Rosemary Smith. The data were organized into sheets, and the format modified to keep a consistent style of data entry across years and sampling sites. Data entries that were extraneous (e.g. beetle or rodent species other than the three main species of focus) or confusing (e.g. blanks and unusual numbers) were deleted. Modifications to the census data were allowed because they did not have any noticeable effects on the overall trends, and improved the interpretability of the large data sets.

The climate data set includes temperature and precipitation measurements for two locations—Kettle Ponds and billy barr. This information was downloaded from the Western Regional Climate Center website (http://www.wrcc.dri.edu/rmbl/). Data for a third location—Schofield Pass—were downloaded from the USDA Natural Resources Conservation Service and National Water and Climate Center website (http://www.wcc.nrcs.usda.gov/index.html), using the Station ID number 737.

The Schnabel method and population index data sets are Excel files contributed by Dr. Rosemary Smith. Both files contain equation templates that were modified to help students understand the order of calculations. The Schnabel method template was populated with data from the rodent census, and the population index template was filled with data from the beetle census. The final data set in the collection, beetle biomass, is a small sample of measurements from biomass conversion test experiments carried out in late 2016 at Idaho State University.

To provide students with more hands-on experience, there are two different laboratory experiments in the module. Both involve live burying beetles. The first is a respiration experiment adapted from a protocol by Vernier Software & Technology (2017). Multiple trials of the experiment were conducted in order to troubleshoot procedural problems and malfunctioning equipment. The second is a biomass conversion experiment adapted from a protocol by Dr. Rosemary Smith for raising burying beetles in captivity. Dr. Smith's publication record also contributes to the module. The articles by Smith and Merrick (2001), and Smith et al. (2000) contain information required to complete the assignments. Students will also need to access a collection of images that includes Google Earth satellite snapshots, a diagram of the sampling sites, a burying beetle identification key, and a graph.

Table 2.2. Learning materials

Folder names	File names
Data sets	Beetle census Rodent census Climate data Schnabel method Population index Beetle biomass
Experiments	Respiration Biomass conversion
Publications	Smith and Merrick 2001 Smith et al. 2000
Images	Maxfield Meadow vs. billy barr Schofield Pass vs. Bellview Sampling sites diagram Rodent-beetle relationship Burying beetle identification key

Teaching Materials

Educators who use the *Tiny Grave Diggers* module are supported by several different resources (Table 2.3). First of these is a framework that links major learning goals with assessment instruments and activities. One learning goal is taken from the Vision and

Change in Undergraduate Biology Education report (American Association for the Advancement of Science 2011), while the other three goals are part of the Ecological Society of America-approved Ecology Learning Framework (Doherty, Ebert-May, and Pohlad 2017).

The second teaching resource is a set of notes, created after testing the burying beetle module and soliciting feedback from students. The notes clarify aspects of the student assignments that might cause confusion, and provide instructions on how to trap burying beetles for the experiments. The third teaching resource is a set of Excel answer keys that show how data should be correctly processed. Only four of the six data sets have a corresponding Excel key (climate data, Schnabel method, population index, and beetle biomass). Because the beetle census and rodent census are analyzed in a program other than Excel they are not included here. The Excel keys were created jointly by two graduate students. Answers were checked multiple times, compared against student work, and verified by supervising professors. The fourth teaching resource is a set of written answers to the student assignments. Answers are based on general ecological knowledge (of the graduate students and supervising professors), feedback from Dr. Rosemary Smith, and reference textbooks. The answer keys were improved multiple times before reaching their final version.

The last teaching resource pertains to the *Tableau* data visualizer, which is used in the student assignments as an alternative to Excel. *Tableau* allows users to connect to spreadsheets and create interactive data visualizations and static graphs. Because students are required to analyze the beetle and rodent census data in *Tableau*, and transfer the results to the sampling sites diagram, the answer key to the diagram is part of the *Tableau* folder. The other *Tableau* related resources are example graphs.

Table 2.3. Teaching materials

Folder names	File names
Learning goals	Module framework ESA ecology learning framework
Notes	Species-habitat interactions notes Population dynamics notes Energy transfer notes
Excel answer keys	Climate data key Schnabel method key Population index key Beetle biomass key
Assignment answer keys	Species-habitat interactions key Population dynamics key Energy transfer key
Tableau	Sampling sites diagram key Beetle population distribution Beetle population size over time Rodent biomass over time Rodent captures at different sites

Implementation and Evaluation

As the main audience for my dissertation is scientists, but this work is very different from scientific research, I would like to justify the methods I elected to use. To start, my classroom study fits perfectly into a category of practitioner pedagogical scholarship called descriptive research (Weimer 2006). According to Weimer (2006, 109), work using this approach does as the name implies: It describes, most commonly by collecting and then analyzing survey data. I did consider other types of practitioner pedagogical research reviewed in Weimer (2006), but found them less suitable to the classroom environment I had access to. It was not possible, for example, to carry out a quantitative investigation using an experimental design. The limited sample size (low student enrolment in General Ecology) precluded a robust comparison between an experimental and control group. Nor was it realistic to conduct a qualitative study using approaches such as participant observation and ethnography. A lack of resources excluded evaluation techniques that required a significant amount of time and number of personnel. That being said, I made great use of what was available: two semesters of General Ecology with an enrolment of ~30 students each, two lab periods to test the module, an assistant to share the teaching load, and sufficient time to complete a short survey and quiz. Perhaps because many faculty face similar situations, descriptive studies are the largest and most well developed kind of practitioner pedagogical scholarship (Weimer 2006, 109). Weimer (2006, 111-112) attributes the quality and value of descriptive studies to four factors: 1) the methods of inquiry fit the phenomena being studied; 2) a sufficient number of subjects are conveniently available; 3) the methods of analysis are well established; and 4) faculty need evidence to assess the impacts of their instruction.

I tested the *Tiny Grave Diggers* module in the undergraduate General Ecology course at Idaho State University. During the Fall 2016 semester, 31 students from three different laboratory sections participated in the module (Table 2.4). During the Spring 2017 semester, 31 students from two different laboratory sections participated in the module (Table 2.5). Each laboratory section met once a week for three hours; two consecutive laboratory periods were required to test the module. Students accessed the module content through my personal website (https://kmrobson.jimdo.com/burying-beetle-module/), and used laboratory computers to complete the assignments. Equipment and materials for the experiments were provided by the Biology department and Dr. Rosemary Smith.

Table 2.4. Assignment of students and instructors to lab sections, Fall 2016

Lab section	1	2	3
Number of students	15	9	7
Instructor(s)	Robson	Robson Condo	Condo

Table 2.5. Assignment of students and instructors to lab sections, Spring 2017

Lab section	1	2
Number of students	15	9
Instructor	Condo	Condo

During the Fall 2016 semester, students viewed the digital stories as a pre-lab assignment and then took a recall quiz and survey about those stories at the beginning of the first lab period. The respiration experiment was completed, and the biomass conversion experiment set up. Students began working on the "Species-habitat interactions" assignment, and were given additional time outside of class to complete it. During the second lab period, students finished the biomass conversion experiment and completed the "Energy transfer" assignment.

During the Spring 2017 semester, students viewed the digital stories as a pre-lab assignment and then took a recall quiz and survey about those stories at the beginning of the first lab period. The biomass conversion experiment was set up, and the "Population dynamics" assignment completed. During the second lab period, students finished the biomass conversion experiment, and completed the "Energy transfer" assignment.

The student survey was vetted by two social scientists at Idaho State University. Having experience in survey research, the scientists made important revisions to the wording and choice of questions used. I administered the evaluation instrument with approval from the Human Subjects Committee at Idaho State University, under protocol IRB-FY2017-61. The survey employs an attitude scale, under the basic assumption that it is possible to uncover a person's beliefs or perceptions by asking them to respond to a series of statements (Lovelace and Brickman 2013, 607). Thus, the main purpose of the survey was to determine if digital stories have a positive impact on students in a science course; more specifically, do students believe that their interest in burying beetles and ecological research increased, do they believe that their understanding of the research process and the large data sets improved, and do they find scientists more relatable. Two survey statements were written to assess each research question (Table 2.6). Three additional statements were included on the survey as a general measure of the stories' perceived impact: I enjoyed watching the digital stories; I made a connection between my personal life and something I saw in the digital stories; I think digital stories are an effective way to communicate scientific information. Students self-assessed by reading a statement, and then selecting a response to describe how they felt about that statement. The survey included nine unique statements, with responses on a five point Likert scale: 1=strongly disagree; 2=disagree; 3=neither agree nor disagree; 4=agree; 5=strongly agree. I used Likert items because they are the most common response formats for attitude scales (Lovelace and Brickman 2013, 607), and because the five response options would increase reliability and produce sufficient variances (Masters 1974). Student participation in the survey was voluntary. Of the 62 students who tested the module, 2 declined to answer the survey. See Appendix B for a copy of the survey.

Table 2.6. Research questions and corresponding survey statements

Questions	Statements
Do students believe that their interest in burying beetles and ecological research increased?	The digital stories increased my interest in burying beetles. The digital stories increased my interest in ecological research.
Do students believe that their understanding of the research process and the large data sets improved?	The digital stories improved my understanding of how to conduct ecological research. The digital stories improved my understanding of the data sets.
Do students find scientists more relatable?	The digital stories helped me relate to the scientist. The digital stories helped me relate to the story narrator.

The recall quiz was administered with approval from the Human Subjects Committee at Idaho State University, under protocol IRB-FY2017-61. The purpose of the quiz was to determine whether or not students could remember specific details and scientific information from the digital stories. A total of 15 questions were constructed: basic recall questions with straightforward answers. The number of questions about each digital story varied based on how useful the stories' information was in terms of learning about burying beetles, the process of field work, and the researchers (Figure 2.2). One digital story was excluded as it did not contain relevant information. To answer the recall quiz, students read a question and then circled a multiple choice response. Of the 62 students enrolled in the General Ecology course, only 53 completed the recall quiz (4 declined to answer, and 5 left the second page blank). Most students were able to complete the survey in two minutes, while the recall quiz required at least five. See Appendix B for a copy of the recall quiz.

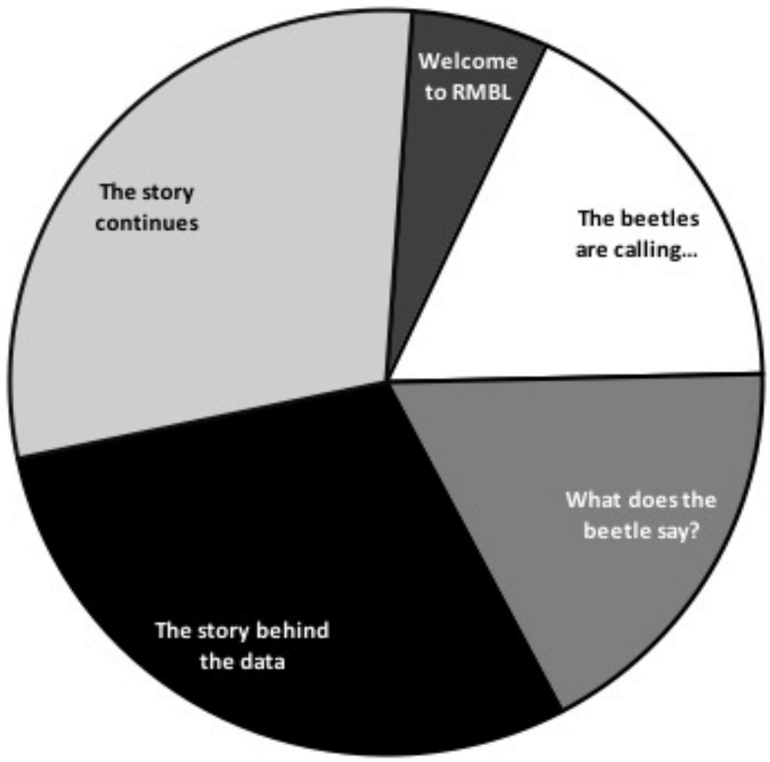

Figure 2.2. Relevance of information in the digital stories to questions on the recall quiz. The size of each slice corresponds to the number of questions.

Results

To present the results of the student survey I used a simple frequency distribution of responses, as recommended by Sullivan and Artino (2013). I found that, overall, the majority of students thought that the digital stories influenced them in a positive way (Figure 2.3). The digital stories substantially increased interest in burying beetles (70% of students affirmed), and ecological research (75% of students affirmed). After watching the digital stories, the majority of students also had a better understanding of how to conduct ecological research (78.3%), and of the data sets (60%). As far as connecting to the main characters of the module, the digital stories helped 78.3% of students relate to the scientist, Dr. Rosemary Smith, and 65.1% of students relate to the narrator. While only a small majority made a connection between their personal lives and something they saw in the digital stories (55%), over 80% of students agreed or strongly agreed with the statement "I enjoyed watching the digital stories," and "I think digital stories are an effective way to communicate scientific information."

To analyze the results of the recall quiz, I first performed one-way ANOVAs. The null hypothesis that lab section instructor (Robson, Robson/Condo, Condo) had no effect on quiz scores was supported ($F=0.06$, $p=0.95$), as was the null hypothesis that semester (Fall, Spring) had no effect on quiz scores ($F=0.08$, $p=0.76$). Given that the scores did not differ significantly across instructors or semesters, I decided to group and present the data (Figure 2.4). The average score was 12.15 out of 15 (81%), and 41 of the 53 students who completed the quiz achieved a score of 12 or higher.

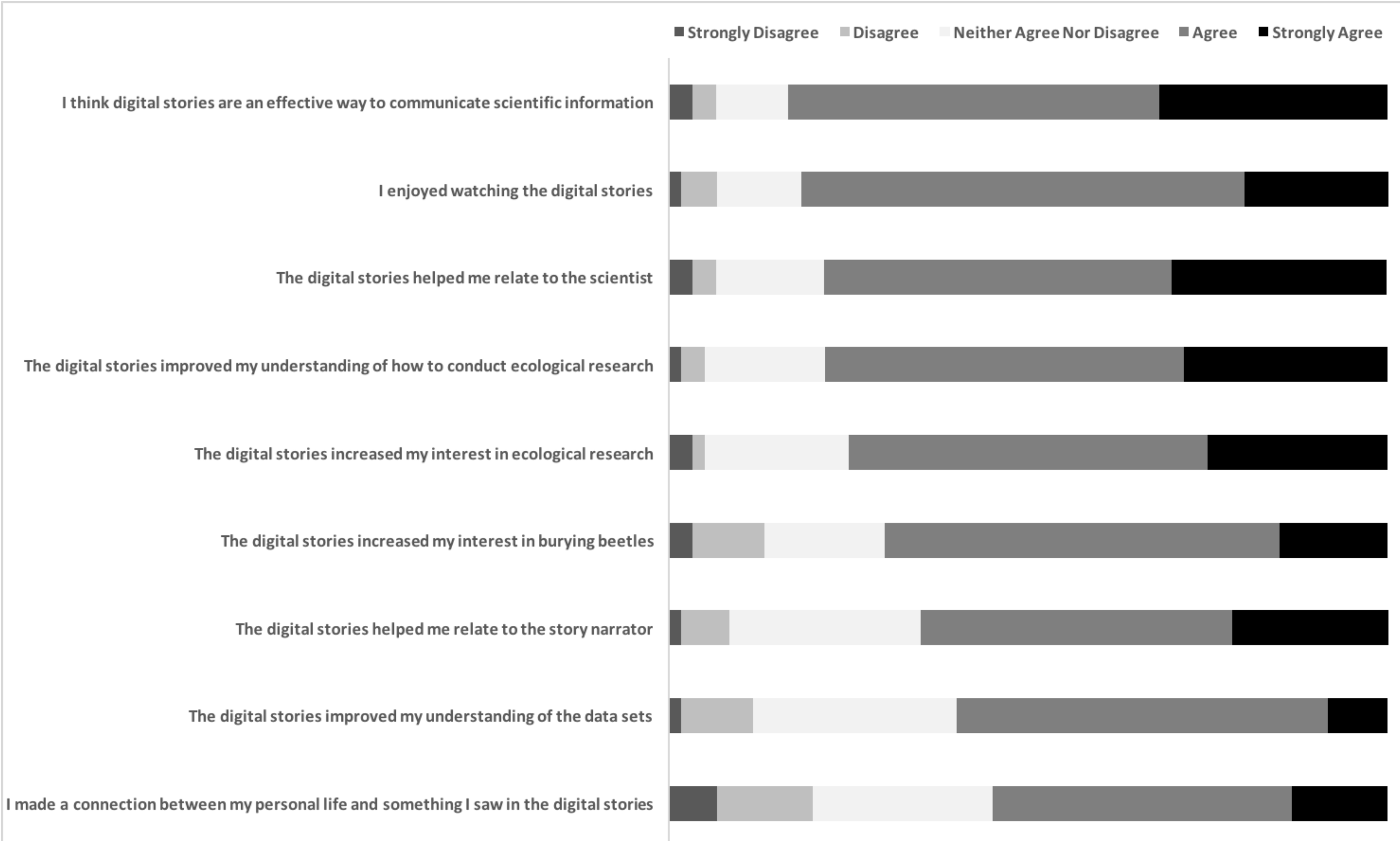

Figure 2.3. Results of the digital story survey. Sample size is 60 students. The shaded sections of each horizontal bar represent the percent of students that selected a particular response.

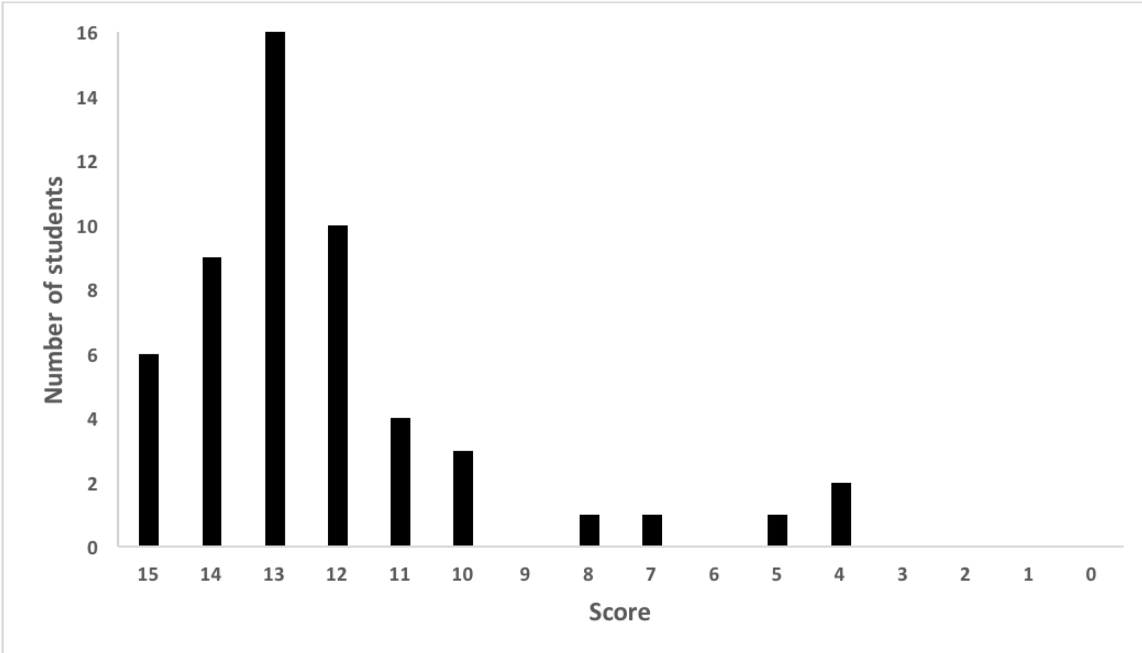

Figure 2.4. Distribution of scores achieved on the recall quiz. Sample size is 53 students.

Conclusions

The results from the survey and recall quiz should be interpreted in the context of a few limitations. First, I did not thoroughly validate the survey and quiz; therefore, the questions may not measure exactly what they were intended to. Second, I constrained the scope and detail of both evaluation instruments to encourage participation. My students were concerned about completing graded assignments during the available class time, and were reluctant to volunteer more than ten minutes of their time to complete a non-essential task. Third, I had a limited sample to obtain feedback from. Despite these limitations, I think it is reasonable to conclude that the survey and recall quiz support the integration of digital stories into science teaching. Overall, students reported that their interest in burying beetles and ecological research increased, the research process and the large data sets were better understood, and a connection was made to the scientists. In my role as a lab instructor, I also received unsolicited, positive feedback from students about the digital stories. The other instructor reported similar behavior, such as several comments from students to the effect of “I remember that from the video!” (personal communication). The results of the recall quiz showed that the majority of students retained a substantial amount of information from the video. Given as a pre-lab assignment, watching the digital stories was an effective way to inform, prepare, and enthuse students for the upcoming lab.

In the context of previously presented literature, my results are expected. For instance, in the introductory chapter I referenced educational studies that showed videos enhance learning, and can be particularly useful in the science classroom. In one such study, Dash et al. (2016) created a video titled “Harry’s Fatty Worries” by combining images, video clips, and narration, and used it to present a challenging topic to pre-clinical teachers. The authors reported that student understanding of fatty liver, along with causes and prevention, significantly increased after watching the video. Similarly, Stockwell et al. (2015, 934) used video assignments in an undergraduate biochemistry course, and confirmed the hypothesis that “video is a more engaging way to present new and complex material to students and stimulates students to be interested in learning more about the topic by attending class.” Although my study did not employ the same evaluation techniques as Dash et al. (2016), and Stockwell et al. (2015), I also found that students’ understanding of, and interest in scientific content improved after watching videos (digital stories). What’s more, substantial agreement with the statements “I think digital stories are an effective way to communicate scientific information,” and “I enjoyed watching the digital stories” lends support to Bell and Bull’s (2010, 1) description of contemporary uses of vides as “casual and conversational;” a primary form of communication among today’s youth.

Baim's (2015) use of digital storytelling is the most comparable to my own. The author developed a video-based learning module based on the best practices of digital storytelling, and used it in online sections of a leadership course. The focal digital story about mentorship was based on a very special, and intensely personal experience from the instructor's past. Just like the comments I received from students, Baim (2015, 56) reported that "feedback on the video has been excellent." Furthermore, the mentorship story was the basis for online, peer-to-peer interactions, as well as an active forum discussion. Student participation was high (Baim 2015). In a related way, the digital stories from the *Tiny Grave Diggers* module initiated discussion. One standout example was a constructive debate between two groups about the "point" of scientific research (i.e. What do we stand to gain from studying burying beetles?). Another was a series of questions from one group about the burial and decomposition process, asked during setup for the biomass conversion experiment. While only 55% of students reported making a connection between their personal lives and something they saw in the digital stories, the video content was interesting and relevant enough to be referred back to by many students.

As previously stated, my aim for this chapter was to convince scientists to incorporate more storytelling into classroom teaching. One approach I encouraged is to create and share personal digital stories; the other is to use the digital story-based module I developed. Regarding the latter, I see some viable next steps. Now that the module is published to the Digital RMBL website, it can be evaluated in more depth. I will make the student survey and recall quiz available to faculty using the module, and will work with the Digital RMBL project manager and content developer to collect and review feedback. Additional input will help validate the evaluation instruments (Evergreen et al. 2011), while replication in different courses (e.g. General Ecology, Field Biology, Entomology, and Introductory Biology), combined with an increased sample size, will permit a more robust analysis. The module itself may continue to grow as content is tested and refined, and the ongoing beetle and rodent censuses generate more data.

Weimer (2006, 117) asserts that the improvement potential of descriptive research exists on several different levels— "the individual faculty member doing the research, other individual faculty who learn about the findings, whole disciplines that may be challenged to consider standards, as well as the entire profession of college teaching" (Weimer 2006, 117). While I do not anticipate that my work will influence an entire profession, I expect it to inform individual practitioners. Scientists in particular should now have a better idea how to use personal digital stories in classroom environments. For future pedagogical research on this topic, however, I recommend an experimental design comparing a non-story control group to an experimental group. Lewis and Lewis (2005) used this approach to evaluate the effectiveness of peer-led guided inquiry (PLGI). The authors compared two sections of a General Chemistry course that were taught concurrently by the same instructor. The experimental section met for two 50-minute lecture sections and one 50-minute PLGI session each week, while the control section met three times each week for 50-minute lectures (Lewis and Lewis 2005). The effectiveness of the PLGI intervention was assessed by administering exams, and comparing the results between sections (Lewis and Lewis 2005). In a similar way, I think a quantitative, comparative approach can be used to rigorously measure the effectiveness of digital storytelling as a science teaching tool.

Telling digital stories in science classrooms is a promising first step towards more widespread use of novel tools in science communication. As the Vision and Change report states, "Practicing the communication of science through a variety of formal and informal written, visual, and oral methods should be a standard part of undergraduate biology education" (American Association for the Advancement of Science 2011, 15). Chapter III will examine this point in more detail, but at the middle and high school level. Specifically, what happens when students become the storytellers?

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Appendix A: Photographs

Title: Confrontation
Photo credit: Kelsey Robson
Description: Size comparison between a burying beetle and a cockroach.

Title: RMBL
Photo credit: Kelsey Robson
Description: View from the entrance of the Rocky Mountain Biological Laboratory.

Title: Levi
Photo credit: Unknown
Description: Dr. Smith and Dr. Williams build Levi cabin.

Title: Alpine Wedding
Photo credit: Unknown
Description: Dr. Smith and Dr. Williams get married at RMBL.

Title: Gravediggers
Photo credit: Kelsey Robson
Description: The first stages of a mouse carcass burial.

Appendix B: Evaluation Instruments

Digital Story Recall Quiz

1. Where did Dr. Smith launch her scientific career?
    - A. At the Rocky Mountain Biological Laboratory.
    - B. At Pomona College.
    - C. At Idaho State University.

2. Dr. Smith's research on burying beetles started as
    - A. a citizen science project.
    - B. a class project with her students.
    - C. an undergraduate research project.

3. Why is rodent trapping important for studying burying beetle population dynamics?
    - A. Because beetles require rodent carcasses for reproduction.
    - B. Because rodents are the primary predators of the beetles.
    - C. Because beetles and rodents compete for the same food source.

4. Beetles account for approximately ____ % of known life on Earth.
    - A. 80
    - B. 1
    - C. 25

5. What is one function of the burying beetle's antennae?
    - A. The antennae contain a toxic chemical that deters predators.
    - B. The antennae are used in a complex mating ritual.
    - C. The antennae contain organs of smell that help locate decaying flesh.

6. Biparental care is unusual in insects, but it is a characteristic trait of the burying beetles. The best description of biparental care in burying beetles is:
    - A. Both parents care for the offspring until the second year of adulthood.
    - B. First the male cares for the eggs, then the female cares for the larvae.
    - C. Both parents care continually for the larvae until they are ready to pupate.

7. Which statement accurately describes the sites where beetle and rodent trapping occurs?
    - A. The three study sites are located along an elevation gradient.
    - B. The 2 study sites are located along an elevation gradient.
    - C. The 3 study sites are all at the same elevation.

8. The beetle traps are baited with
    - A. a scoop of meal worms.
    - B. a rotting chicken drumstick.
    - C. fresh flowers.

9. The three different species of burying beetle are identified by
   A. The color of the antennae, elytra, and metapimeron.
   B. The shape of their wings.
   C. A characteristic pattern on the thorax.

10. How are beetles marked for the mark and recapture study?
   A. With a dot of paint on the elytra.
   B. Using a fine insect pin to pierce the elytra.
   C. By cutting a small notch into the elytra.

11. Which statement best describes how beetle traps and rodent traps are set up?
   A. Beetle traps are set across a 7 x 7 grid system; rodent traps are set 20 m apart along a transect.
   B. Beetle traps are set 20 m apart along a transect; rodent traps are set across a 7 x 7 grid system.
   C. Beetle traps are set 20 m apart along a transect; rodent traps are set 20 m apart along a transect.

12. What materials inside the rodent traps help alleviate stress on the animal?
   A. A handful of bait for food and a "polyester sleeping bag" for warmth.
   B. A block of cheese for food and a wool sock for warmth.
   C. A scoop of meal worms for food and woodchip bedding for warmth.

13. Why is it important to finish the rodent survey early in the morning?
   A. Because the rodents need a full day to collect food.
   B. Because it is harder to handle the rodents if they have been in the traps for a long time.
   C. Because the rodents are nocturnal and need to return to their burrows.

14. How are rodents marked for the mark and recapture study?
   A. With a coloured tag in the ear.
   B. With a spot of dark hair dye on the belly.
   C. With an ID band around one leg.

15. Which statement accurately describes Dr. Smith's burying beetle research?
   A. A finished project that sampled beetles at the same sites for many years.
   B. An ongoing project that has sampled beetles at the same sites for a couple of years.
   C. An ongoing project that has sampled beetles at the same sites for many years.

Student Survey

What is your gender identity?

- ○ Male
- ○ Female
- ○ Other: ____________________

What is your age?

- ○ 17-21
- ○ 22-26
- ○ 26+

For each of the questions below, circle the response that best describes how you feel about the statement.

	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
1. I enjoyed watching the digital stories.	1	2	3	4	5
2. I made a connection between my personal life and something I saw in the digital stories.	1	2	3	4	5
3. The digital stories increased my interest in burying beetles.	1	2	3	4	5
4. The digital stories increased my interest in ecological research.	1	2	3	4	5
5. The digital stories improved my understanding of how to conduct ecological research.	1	2	3	4	5
6. The digital stories improved my understanding of the data sets.	1	2	3	4	5
7. The digital stories helped me relate to the scientist.	1	2	3	4	5
8. The digital stories helped me relate to the story narrator.	1	2	3	4	5
9. I think digital stories are an effective way to communicate scientific information.	1	2	3	4	5

Chapter III

Classroom Storytelling Culture

"If you tell me I will listen. If you show me I will see. If you let me experience, I will learn."
–Lao-Tzu

Classrooms are an ideal place for story training and development. In the preceding chapter I encouraged scientists to integrate digital storytelling and teaching, and as a practical example, described the implementation of the *Tiny Grave Diggers* module. Throughout, students remained seated in the audience. Now it is time for a new challenge. *What happens when students create and share digital stories?* I begin this chapter with a review of studies that support the use of digital storytelling in science classrooms (adding to the literature presented in Chapter II). I introduce the learning theories of constructivism and constructionism, and use them to explain how the process of digital storytelling results in learning. Then, I narrow the focus to middle school and high school classrooms, and demonstrate how digital storytelling aligns with science education standards. Finally, I present four case studies of digital storytelling integration, describing a teacher workshop I delivered, and the digital storytelling projects I helped implement in middle school and high school science classrooms. For each project, I measured student attitudes, elicited teacher feedback, and evaluated strengths and weaknesses. Given this evidence, I will then make recommendations for improved practice and discuss broader implications.

Student Storytellers

The American Association for the Advancement of Science (1990) describes science as a complex social activity: "Scientific work involves many individuals doing many different kinds of work and goes on to some degree in all nations of the world. Men and women of all ethnic and national backgrounds participate in science and its applications." Because of the social nature of science, effective communication and dissemination are essential to progress. Being able to create and tell a good story are thus invaluable skills. Coskie, Trudel, and Vohs (2010, 3) observed that "when students learn to tell stories, they learn to speak for a specific purpose, to carefully attend to an audience, to highlight non-verbal information, to develop effective presentation skills, and to love public speaking." Hartsell (2017) recommends digital storytelling, specifically, for building confidence and encouraging self-expression. Indeed, all these attributes are important if we expect our students to provide a voice for the scientific community and participate in society. Robin (2008, 221) also points out that today's students belong to a "new generation of not just information gathering, but information-creating as well." Because digital storytelling improves students' media literacy (Ohler 2006), it better prepares them to communicate science in our contemporary, online culture of handheld devices and social networking. Without these sorts of skills, scientists remain dependent on journalists or "middlemen" to translate their work (sometimes incorrectly), and lose the opportunity to directly engage with the public.

Recognizing the need for improved science communication, many educators are rising to the occasion. For instance, Ohler (2006, 47) describes a digital storytelling activity with preservice teachers at the University of Alaska. One of the stories, titled *Bob's Battle*, is a cautionary tale about superbugs.

> Bob tries to discover why he can't manage to shake an illness despite treatment from his doctor. It turns out that Bob did not complete his full course of antibiotics and has created a colony of superbugs resistant to his medication. The story is packed with scientific illustrations, diagrams, and data that support the narration. In the end, Bob admonishes the viewer, "Don't mess around with antibiotics." (Ohler 2006, 47)

Bob's Battle is so much more compelling than a scientific report about drug resistant bacteria because it is centered around a character with a problem. Quite unconsciously, the watcher is transported into the story, searching for a resolution: Will Bob defeat his illness? The narrative structure wraps scientific facts into an inviting and memorable package; the type of package we regularly receive from newspapers, magazines, social media, and other online sources. If we teach our students to talk about science in the universal language of stories, we promote a more open, inclusive dialogue between the scientific and public community. In the next few paragraphs I will describe science classrooms where students tell their own stories, and provide specific examples of these digital tales.

Frazel (2010, 138) believes that, "Students who are inspired by the wonder of nature and possess natural curiosity about the scientific world will find their own level of emotional connection to tell the stories of their future plans for invention, medicine, and even saving the planet." To this end, Hung, Hwang, and Huang (2012, 372) combined digital storytelling and project-based learning in an elementary school science unit called "I am the energy-saving master." The unit was composed of five different learning tasks, such as "How to save energy," and "Comparing the energy consumption of household appliances" (Hung, Hwang, and Huang 2012, 372). Students collaborated to complete each task; how this was accomplished, and the resulting product, differed depending on which group the students were randomly assigned to. For example, students in the control group used a project-based learning approach and created a traditional PowerPoint to present their findings and conclusions; in contrast, students in the experimental group used both a project-based learning and digital storytelling approach, and created a digital story to present their results (Hung, Hwang, and Huang 2012, 372-374). The authors used several different instruments to compare the control group and experimental group: a science learning motivation scale, a problem-solving competence scale, a science achievement test, and student interviews. Science learning motivation was significantly higher for students in the experimental group, as was problem-solving competence and science achievement (Hung, Hwang, and Huang 2012, 374-375). An opinion expressed by many students in the experimental group was that digital storytelling was "a more interesting way of learning" (Hung, Hwang, and Huang 2012, 376). The authors conclude by saying, "It is reasonable to owe the success of this project-based learning activity to the digital storytelling approach since it provides not only an interesting way for the students to present their findings, but also an opportunity for them to conduct active learning and organize their knowledge" (Hung, Hwang, and Huang 2012, 376).

Prud'homme Généreux and Thompson (2008, 25) praise digital stories as "a very effective method of supporting student reflection upon learning in a way that is highly attractive to students." The authors speak from their experience leading a digital storytelling workshop, the closing activity for an undergraduate Ecology, Evolution, and Genetics course. Students were asked to consider how the course had changed their perception of either ecology or genetics, and express their thoughts in a digital story. Prud'homme Généreux and Thompson (2008, 24) observed that many students became “very involved” with the digital storytelling process, and several produced “outstanding movies; they were highly creative and included insightful reflection, interesting and effective narration, and good video graphics and sounds.” For example, one student submitted a digital story that depicted relationships among classmates in terms of the concepts and terminology of community ecology. When surveyed after the workshop, many students expressed surprise at how “simple, narrow, or naïve their perspectives had been just two months earlier” (Prud’homme Généreux and Thompson 2008, 24). This type of metacognition is extremely valuable. Digital storytelling engages students in frequent reflection, from thinking about past experiences, to adjusting visual elements to convey a particular message, to realizing the discrepancy between what was thought to be learned, and what was actually learned. McDrury and Alterio (2003, 21) state that “the process of reflection involves the self and the consequence of reflection is a changed conceptual viewpoint.” Achieving this sort of result in a science class is commendable.

Frazel (2010) uses the topic of weather as her go-to example of scientific digital storytelling. She describes a project where young students investigate the science behind storms, conduct oral interviews, and locate historical photos of natural disasters. A certain amount of creativity is required to weave scientific information into a digital story about how people’s lives are impacted by everything from powerful hurricanes to springtime blizzards. With this same creativity, digital storytelling can be used to address any science topic. For example, preservice teachers at Dicle University created digital stories about color blindness, mutualism, the human immune system, features of a cell, Down syndrome, and spider webs, just to name a few (Karakoyun and Yapici 2016, 899). The teachers reported that learning through digital storytelling was more active and engaging, and that the process improved their research and technology skills (Karakoyun and Yapici 2016, 899). Extrapolating to their own classrooms, the teachers predicted that the digital storytelling process would increase student learning, and improve the permanency of that knowledge (Karakoyun and Yapici 2016, 899).

Robin's (2017) website is a popular resource for educators entering the world of digital storytelling. The "Example Stories" tab has a collection of over 175 digital stories. To date, the Science category contains eighteen digital stories, with titles such as "The Idea Maker Evolution," "Map the Moon," and "Energy of Ocean Currents" (Robin 2017). Robin's (2017) website is a good resource for teachers trying to imagine the diversity of topics to which digital storytelling can be applied; in some cases, the website also provides examples of what *not* to do (such as fill a five-minute video with stock photos from the Internet, or use a voiceover that is barely audible). A similar, but smaller collection of digital stories is maintained by Kevin Gortney, a science teacher from Presidio Middle School (Werby 2012, 23). Gortney's website (http://kgortney.pbworks.com/) features a "Digital Storytelling Project Stop Action Movie Hall of Fame," with links to several student-made videos. It is encouraging to learn that Gortney teaches four science classes, with an average of 31.6 students in each class, but is still able to help his students complete as many as three digital stories per school year (Werby 2012, 23-24). So…it can be done, it has been done, and the effort is worth the reward. But how exactly will making a digital story help our students learn? The process is better understood if we examine it through the lens of constructivism.

A Way to Construct Knowledge

Constructivism is a prominent learning theory with relevance to science education. It is the basis for inquiry methods that emulate "what scientists do to investigate the natural world," and thereby a foundation of the Next Generation Science Standards' "Science and Engineering Practices" (Next Generation Science Standards 2017). It is also a theoretical framework for many educational studies in the STEM fields (e.g. Carpenter et al. 1999; Davis, Maher, and Noddings 1990; Moreno et al. 2007; Wu and Tsai 2005). However, frequent reference to constructivism is complicated by the fact that there are different interpretations of the theory (Tobin 1993). My purpose here is not to provide an exhaustive review, nor to wade too far into philosophical waters. Instead I will describe how constructivism informs educational practice, and then focus on one interpretation that explains how digital storytelling contributes to knowledge construction in the classroom.

At its simplest, constructivism posits that "ideas are constructed from experience to have a personal meaning" (Powell and Kalina 2009, 241). Resnick (1989, 1) elaborates: "First, learning is a process of knowledge *construction*, not of knowledge recording or absorption. Second, learning is *knowledge-dependent*; people use current knowledge to construct new knowledge. Third, learning is highly tuned to the *situation* in which it takes place." From this description we might start to see why constructivism, as a theory of learning, doesn't directly translate into a practice of teaching (Richardson 2003). Llewellyn (2013, 65) offers a definition that brings us closer to the classroom: "The student is embedded in active engagement and is constantly constructing and reconstructing knowledge through hands-on interactions." However, certain types of interactions and activities are superior to others. Fosnot and Perry (2005, 33-34) recommend that teachers:

1) allow students to ask questions and test hypotheses; 2) pose challenging, open-ended investigations; 3) explore contradictions; 4) provide reflection time; and 5) encourage students to engage in dialogue. A similar, and even more detailed list is offered by Windschitl (2002, 137). Taken as a whole, the ultimate goal of constructivist instruction is cognitive development and deep understanding (Fosnot and Perry 2005, 10); the role of the teacher is best described as a facilitator and motivator.

Digital storytelling is a useful tool for a constructivist classroom. Behmer's (2005, 4) definition of storytelling— "A process where students personalize what they learn and construct their own meaning and knowledge from the stories they hear and tell"—makes the connection explicit. However, we will look specifically at the theory of cognitive constructivism (also known as individual or psychological constructivism), to gain a better understanding. Cognitive constructivism derives mainly from the ideas of Jean Piaget; within the pages of *The Origins of Intelligence in Children,* he advanced the notion that children construct their own understanding of the world through active and sensorial explorations of their environment (Burnett 2010, 146). Piaget aims to explain how learners, as individuals, impose intellectual structure on their worlds (Piaget 1971). Many practitioners claim that cognitive constructivism underlies their teaching methods; however, these claims are often riddled with misunderstandings (Baviskar, Hartle, and Whitney 2009). Hartle, Baviskar, and Smith (2012) offer a solution: A field guide to cognitive constructivist teaching.

Using a digital storytelling project in a science course satisfies all the criteria on the field guide (Table 3.1). In fact, it is even possible to meet the criteria twice over (distinguished by the series of capital or lowercase letters, Table 3.1). Let me provide a more concrete example. A student has been asked to create a digital story that answers the question, "Which ecosystem service is most valuable to you?" To begin, the student creates a table that matches past experiences (such as eating fruit from an apple tree, or hiking through a forest) with new concepts (such as provisioning services and cultural services). Criteria 1 is met. Next, the student drafts a story with her answer to the question. She finds it difficult to adapt her facts about cultural ecosystem services to Freytag's Pyramid structure. Using a story to explain science feels uncomfortable. Criteria 2 is met. Then, the student reads her story to a peer and asks for feedback (e.g. Did the story present a problem and resolution? Do you understand what cultural ecosystem services are?) The student repeats this process with another peer, and revises her story script based on the feedback. Criteria 3 is met. Finally, the student records a voiceover of the script, and listens to the playback. Because the voiceover is the backbone of the digital story, the student must ensure that her answer to the assignec question is solid before moving on to the storyboard. Criteria 4 is met.

Table 3.1. Match between field guide criteria and stages of digital storytelling.

Criteria	Stages (student actions facilitated by the teacher)
1. Eliciting prior knowledge	A. Making a personal connection to a science concept. a. Collecting personal media.
2. Creating cognitive dissonance	B. Writing the story script about a science concept. b. Using media to explain a science concept.
3. Application of new knowledge with feedback	C. Sharing and revising the story script. c. Sharing and revising the storyboard.
4. Metacognition	D. Recording and listening to the voiceover. d. Producing and watching the digital story.

Source: Criteria from Hartle, Baviskar, and Smith 2012, table 1

Schrader (2015, 30) says the following about a platform to which digital stories are well suited: Social media "engages learners creatively in the teaching-learning process…they become more expert with the tools and create new cultural artifacts that are afforded by the available technologies." Labelling digital stories as "new cultural artifacts" leads us to another theory of learning: Constructionism.

> "Constructionism—the N word as opposed to the V word—shares constructivism's connotation of learning as "building knowledge structures" irrespective of the circumstances of the learning. It then adds the idea that his happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe." (Papert and Harel 1991)

Or, a digital story. The theory of constructionism was first proposed by Seymour Papert (1980). In an essay titled *Situating Constructionism*, Papert describes an art room he used to pass everyday on the way to his math classroom (Papert and Harel 1991). The students inside were carving soap; each individual sculpture came from "wherever fancy is bred," and the project continued for many weeks. According to Papert, this allowed "time to think, to dream, to gaze, to get a new idea and try it and drop it or persist, time to talk, to see other people's work and their reaction to yours—not unlike mathematics as it is for the mathematician, but quite unlike math as it is in junior high school." Papert recalls that he obsessed over the soap sculptures, but was struck by the incongruous idea of pining after his students' math homework. Thus, Papert devised an idea that he dubbed "soap-sculpture math." The basic premise is that students learn by making; that working with concrete materials is easier than working with abstract propositions. Herein lies the value of digital storytelling to science education. For instance, I recently worked with a group of high school chemistry students; their challenge was to create a digital story that featured three items of personal importance, and explain the chemical composition of each item. Students had to draw models of chemical compounds, find images of different materials, use sounds to signify a chemical reaction, and various other tasks that turned their abstract ideas into concrete media.

In *Situating Constructionism*, Papert tells another story about student creations; not soap sculptures this time, but digital spaceships (Papert and Harel 1991). He remembers that the first space shuttle was about to launch and evidence of the excitement appeared in students' Logo programming projects. But although everyone was building spaceships on screen, they were not making them the same way—there were distinct differences in *style*. Digital storytelling is like Logo programming in the sense that it allows for freedom of creation and expression. Kynigos and Futschek (2015) describe how constructionism emphasizes the use of digital media as a way for students to externalize meaning and make their ideas public. Papert proposed the notion of a "microworld" to describe digital artifacts: self-contained worlds where students learn to "transfer habits of exploration from their personal lives to the formal domain of scientific construction" (Papert 1980, 177). This description is close to the mark of digital storytelling. Hoban, Nielsen, and Carceller (2010) observed that by creating a digital artifact, students clarified, checked, and refined their understanding of a science concept. In this case the artifact was a "Slowmation": a simplified way of making an animation that integrates features of object animation and digital storytelling (Hoban, Nielsen, and Carceller 2010, 438). The authors add, "because the technology is relatively easy and accessible…the approach has possibilities for widespread use in universities and schools" (Hoban, Nielsen, and Carceller 2010, 441). It is only natural that "learning by making" in a digital age should involve activities such as recording voiceovers, editing photographs, and producing videos.

An Answer to the Next Generation Science Standards

The Next Generation Science Standards (NGSS) were developed to address the "leaky" pipeline of Science, Technology, Engineering, and Mathematics (STEM) education in the United States. Implementing the standards, or goals, is expected to produce high school graduates better prepared for the demands of college and careers (Next Generation Science Standards Lead States 2013e); students whose scientific knowledge is backed by transferable skills such as problem solving and communication. The Next Generation Science Standards Lead States (2013e, 1) place educational reform in the context of society: "Never before has our world been so complex and science knowledge so critical to making sense of it all. When comprehending current events, choosing and using technology, or making informed decisions about one's healthcare, science understanding is key." The NGSS are a roadmap to achieving this understanding; however, there is no prescribed method for teaching the standards. Instructional decisions are left in the hands of states, districts, schools, and teachers. As such, digital stories are a legitimate tool for science educators to use. What's more, the digital storytelling process aligns with practices, themes, and literacy standards described in the NGSS appendices.

Appendix F describes the eight science and engineering practices that students are expected to learn; "obtaining, evaluating, and communicating information" is one of them (Next Generation Science Standards Lead States 2013a, 1). Scientists need to be able to share their ideas with the broader public. However, because this is not an easy skill to master, training and practice should start early. We must also acknowledge that, "Communicating information, evidence, and ideas can be done in multiple ways: using tables, diagrams, graphs, models, interactive displays, and equations as well as orally, in writing, and through extended discussions" (Next Generation Science Standards Lead States 2013a, 15). Digital storytelling provides relevant communication practice. For example, the NGSS expect students in grades 9-12 to "communicate scientific and/or technical information or ideas…in multiple formats (i.e., orally, graphically, textually, mathematically)" (Next Generation Science Standards Lead States 2013a, 15). Thus, as an alternative to the typical science fair poster, students could create a digital story about a hypothesis they tested. Writing the story script, recording the voiceover, and combining the video clips and images would provide practice in multiple mediums of communication.

Appendix H focuses on an important goal of science education: Helping students understand the nature of scientific knowledge (Next Generation Science Standards Lead States 2013b). To this end, there are many different ways that digital storytelling can contribute. For example, middle school students need to appreciate how "men and women from different social, cultural, and ethnic backgrounds work as scientists and engineers" (Next Generation Science Standards Lead States 2013b, 6). Students could create a digital story about a scientist that they identify with, investigating why the person chose that career, and how they became successful in it. High school students need to realize that "many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues" (Next Generation Science Standards Lead States 2013b, 6). Students could thus create a digital story about a contentious issue that affects them (for example, the reintroduction of wolves to Yellowstone National Park for students in neighboring states), explaining their position, an opposing viewpoint, and how scientific evidence must be weighed against the interests of multiple stakeholders.

Appendix J focuses on the science, technology, and society (STS) theme (Next Generation Science Standards Lead States 2013c). There are two complementary parts: "The first is that scientific discoveries and technological decisions affect human society and the natural environment. The second is that people make decisions for social and environmental reasons that ultimately guide the work of scientists and engineers" (Next Generation Science Standards Lead States 2013c, 2). Digital storytelling, with its emphasis on personal expression and reflection, can help students engage with the STS theme. For example, one idea that students in grades 9-12 will encounter is, "New technologies can have deep impacts on society and the environment, including some that were not anticipated" (Next Generation Science Standards Lead States 2013c, 4). Students could make a digital story about advances in stem cell research, identifying ethical dilemmas, and presenting their personal opinion on the issue. Another example refers an idea that students in grades 6-8 are presented with: "All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment" (Next Generation Science Standards Lead States 2013c, 3-4). Students could make a digital story that details their daily and monthly individual carbon footprint, and proposes reasonable ways to reduce carbon emissions.

Appendix M maintains that "literacy skills are critical to building knowledge in science" (Next Generation Science Standards Lead States 2013d, 1). As such, the NGSS development team has identified key connections between scientific practices and the Common Core Literacy Anchor Standards (Next Generation Science Standards Lead States 2013e). For instance, it is important to recognize that, "writing and presenting information orally are key means for students to assert and defend claims in science, demonstrate what they know about a concept, and convey what they have experienced, imagined, thought, and learned" (Next Generation Science Standards Lead States 2013d, 1). The digital storytelling process is particularly relevant to the scientific practice of "obtaining, evaluating, and communicating information," and its associated literacy standards (NGSS Lead States 2013d, 14-16). For example, the Speaking and Listening Standard 5 expects students in grades 9-12 to be able to "make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence" (Next Generation Science Standards Lead States 2013d, 16). The Speaking and Listening Standard 4 expects students in grades 9-10 to be able to "present information, findings, and supporting evidence clearly, concisely, and logically" (Next Generation Science Standards Lead States 2013d, 16). Both standards are met when students create a digital story: during production, many different types of media are combined in a video editing program to enhance the message of the voiceover; during preparation, narrative structure is used to write a clear and compelling script. Ohler (2006, 47) maintains that "digital stories develop a number of digital, oral, and written literacies in an integrated fashion."

From the evidence presented in the Theory section, I conclude that digital storytelling can improve communication skills, help students learn, and address science education standards. More broadly, digital storytelling is an excellent tool for science communicators. Although the majority of science communication training targets graduate students, early career scientists, and professionals, there is no downside to starting earlier. Thus, I decided to engage middle school and high school students with digital storytelling projects. Four relevant case studies will follow.

Introduction

I trained teachers in the use of digital storytelling technology, assisted with classroom implementation, and then evaluated and reflected critically on the experience. The teacher training took place at Idaho State University during the first week of June, 2016, with twelve teachers enrolled in an Adventure Learning workshop. The workshop was part of the education component of a large, multidisciplinary project called Managing Idaho's Landscapes for Ecosystem Services (MILES). Acceptance to the workshop was competitive: Teachers completed an application form and answered questions such as, "Please describe how participating in MILES Adventure Learning would benefit you professionally," and "Please describe how participating in MILES Adventure Learning would benefit your students." The intent was for teachers to process what they learned at the workshop, and bring it back to their respective schools. In such a manner, information and skills would be disseminated to a broader community of students and educators. The workshop was an ideal context for digital storytelling because it emphasized active learning and non-traditional approaches to science education. What's more, the learning approach adopted for the workshop (a coupling of Adventure Learning and place-based education principles) complimented the digital storytelling process. Workshop leaders made the following comment about the approach they chose:

> Guidelines for teachers and students include collecting media that can be shared easily with limited editing via the online environment; archiving local issues and the authentic narrative associated with the issues; and highlighting the science of local spaces by capturing media that will communicate the science of a place or people." (Miller, Hougham, and Eitel 2013)

On the first day of the workshop I introduced teachers to the digital storytelling process, showed examples of a finished product, and provided a step-by-step guide to follow. I then identified the challenge: Create a digital story that expresses your own, unique answer to the question, “Which ecosystem service is most valuable to you?” Teachers began writing their scripts, peer reviewing, recording voiceovers, and constructing a storyboard. The activity lasted about 1.5 hours. Later, during workshop downtime and at home, teachers continued work on their stories. Next, I introduced the video-editing software WeVideo (http://www.wevideo.com/), and offered a short tutorial on how to use the online technology. Teachers uploaded media and began story composition. The activity lasted about 2 hours; half of the teachers produced a digital story at the end of that time, and half applied finishing touches at home. On the last day of the workshop I premiered all the digital stories on a projector screen. Although we had just spent a week interacting, I noticed that the digital stories revealed new aspects about each teacher’s life. What’s more, several teachers referenced the digital storytelling activity on a comment sheet turned in at the end of the workshop; for example, “I learned about telling stories to teach—using the correct borders and boundaries to be ‘heard,’ and digital media to engage the students.”

I followed up with the twelve workshop participants in December, 2016. In response to my email, two teachers explained that they had already used digital storytelling in their classroom, and four indicated that they wanted to do so in the future. I reached out to the four hopefuls—referred to here by the pseudonyms Teacher A, Teacher B, Teacher C, and Teacher D (Figure 3.1). In January, 2017, I increased email correspondence, drafted assignments for the students, and prepared instructional materials for the teachers (see

Appendix D for examples). Each teacher received two classroom visits which were structured like the workshop: the first visit introduced students to digital storytelling, and focussed on script writing, voice recording, and media collection; the second visit launched the WeVideo editing software, and directed students through the stages of video composition. My role in the classroom was primarily that of facilitation and technical support. I encouraged the teachers to take a leading role in the digital storytelling process, building the confidence and skills necessary to direct future projects.

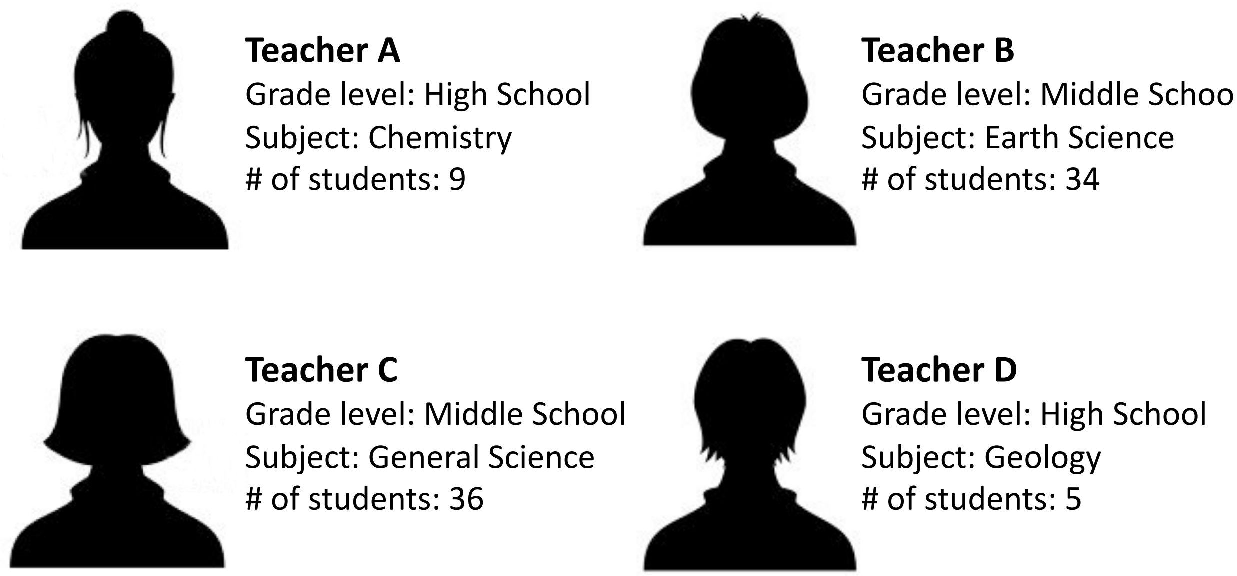

Figure 3.1. Profiles of the four science teachers involved in the case study.

I expected the digital storytelling projects to achieve the following four goals: 1) Increase interest in the course subject matter; 2) Make classroom learning more relevant; 3) Facilitate communication through a digital medium; and 4) Be a positive experience. Two student surveys were developed to evaluate the project goals. The surveys employ an attitude scale, under the basic assumption that it is possible to uncover a person's beliefs or perceptions by asking them to respond to a series of statements (Lovelace and Brickman 2013, 607). Thus, the surveys measured the extent to which students believed that their interest in the subject matter increased, that what they learned in class was relevant, that they could communicate through a digital medium, and that the experience was enjoyable. Multiple survey statements were linked to each project goal (Table 3.2). The surveys were vetted by two social scientists at Idaho State University. Having experience in survey research, the scientists made important revisions to the wording and choice of questions used.

Students participated in the two surveys at the end of the classroom visits —one after making a digital story, the other after watching classmates' digital stories. Students self-assessed by reading a statement, and then selecting a response to describe how they felt about that statement. Each survey included eight unique statements, with responses on a five point Likert scale: 1=strongly disagree; 2=disagree; 3=neither agree nor disagree; 4=agree; 5=strongly agree. I used Likert items because they are the most common response formats for attitude scales (Lovelace and Brickman 2013, 607), and because the five response options would increase reliability and produce sufficient variances (Masters 1974). Student participation in the surveys was voluntary. In addition to the surveys, I gave teachers an open-ended questionnaire to uncover more details about the digital storytelling experience. The questionnaire included nine items, and required between 30 and 60 minutes to complete. All evaluation instruments were administered with approval from the Human Subjects Committee at Idaho State University, under protocol IRB-FY2017-96. See Appendix E for copies of the student surveys and teacher questionnaire.

Table 3.2. Survey statements used to evaluate the goals of the digital storytelling projects

Goals	Survey Statements
Increase interest in the course subject matter	The digital story I made increased my interest in _____. The digital stories increased my interest in _____.
Make classroom learning more relevant	Making the digital story helped me connect my life outside the classroom with what I learn inside the classroom. I made a connection between something in my own life and something I saw in the digital stories. Creating the digital story helped me understand why it is important to learn about _____. The digital stories helped me understand why it is important to learn about _____.
Facilitate communication through a digital medium	The online video editor was easy to use. The digital stories helped me relate to my classmates. I have more respect for my classmate's opinions after watching their digital stories. I think digital stories are a good way to share science-related information.
Be an enjoyable experience	I liked making the digital story. I liked watching the digital stories. I would like to make another digital story as a school project.

Case Study 1: High School Chemistry

Project Overview

Teacher A requested a worksheet to help direct her students through a chemistry-themed digital storytelling project. A section of the document I created is copied below:

> Prompt: Do you remember "show and tell" from your early years of school? What did you bring in to show your classmates? What would you bring in now?
>
> Instructions:
> 1. Pick <u>three</u> different objects that define who you are. These can be objects that you use every day, objects from your past, or objects with a special meaning.

2. Investigate each object and consult other sources (textbook, internet, etc.) to determine what chemical compounds each object is made from.
3. Identify the elements that each chemical compound is composed of.
4. Create a digital story that answers both of the questions below:
    a) What three objects define who you are as a person?
    b) What is the chemistry of these three objects?

The nine participating high school students produced digital stories that were incredibly unique. For example, one student used her favourite activity—playing piano—as the unifying theme for her digital story. First she explored the chemical composition of sheet music, from the calcium carbonate in the paper to the glucose in the ink. Then she described the materials for the shoes she wears to play piano, and finally, the mixture of organic molecules in the cupcakes she treats herself to afterwards. Another student started her digital story with a photo of a snow globe collection. She deconstructed the gifts into their main parts: glass dome, ceramic base, and watery interior. The magical snow? Just a simple trick with benzoic acid. Teacher A noted how "watching the stories surprised many students with the diverse interests of their classmates." On the survey, 67% of students agreed or strongly agreed with the statement "I have more respect for my classmate's opinions after watching their digital stories" (Figure 3.2). Teacher A also observed that "students were surprised that everything around them has its own unique chemistry." As the stories began to take shape, students were asking questions about polymers and organic chemistry—topics more common in university level courses. One student even explored materials science (she developed a keen interest while researching the chemical composition of her knee brace). The survey statement, "Creating the digital story helped me understand how a knowledge of chemistry can be applied in the real world," achieved a high mean score of 4.0 (Figure 3.3).

Challenges

Although the digital storytelling project made classroom learning more relevant, it was an experience plagued with technical difficulties. Teacher A admitted that the class was “bogged down in the technology a bit,” possibly because “the software was a trial.” Although I was able to provide technical support during the classroom visits, most of the problems with WeVideo occurred outside that time. Teacher A reported high levels of student frustration, and many digital stories had glaring technical issues. For instance, a voiceover that was hard to hear over loud, background music, or images that did not fit properly on the screen. Possibly as a result of the technical challenges, the digital storytelling project didn’t score well as an enjoyable experience: Students rated the statement “I would like to make another digital story as a school project” with a low mean score of 2.6, and the statement “I liked making the digital story” with a low mean score of 2.8 (Figure 3.3). Teacher A insisted that her students “all benefitted from the digital storytelling project in some way,” but that in the future she would “seek other software” for classroom implementation.

Teacher A was not the only participant in my case studies to encounter technical difficulties; in fact, technology is arguably the biggest deterrent against digital storytelling. Sadik’s (2008, 501) observations in large classes of middle school students are a fitting example:

> Data gathered from teachers revealed that teachers and students faced many technical and computer difficulties and need more technical assistance to use technology in the classrooms. In addition, teachers indicated that the lack of equipment (such as computers, digital cameras, scanners) and limited access to the Internet discourage teachers and students from successfully using the technology.

Werby (2012, 25) offers the unique perspective of a “producer mom” whose child was involved in digital storytelling projects. She cautions that a successful digital story requires a great deal of technical and logistical support, and that this responsibility sometimes lands on the parents. Thus, differences in the quality of student stories are largely a result of different home environments—some parents can contribute their time and expertise to the digital storytelling project, while others cannot. This situation sounds remarkably similar to a children's science fair, where impeccable (parent-made) poster boards stand next to more modest (student-made) displays. This is *not* the intended outcome of digital storytelling. As Ohler (2006) says, "The focus should be on the story first, and the technology second."

Solutions

Digital storytelling is a powerful tool for science educators; I cannot emphasize this enough. However, it is not a quick and simple undertaking. Consider Teacher A: As an online participant in the MILES Adventure Learning workshop, she didn't create a digital story alongside the other teachers, and hadn't used the WeVideo software before. Her battle with technology offers a warning to fellow educators. Do not ask your students to make a digital story until you have made one yourself. Use the same software, the same internet connection, the same device, and the same equipment that your students will be working with; create your story in the same classroom environment that your students will be working in. Put yourself in their shoes. Create your first digital story over a school break or sabbatical—allow time to troubleshoot problems and learn from your mistakes. As a result, you'll have an exemplary digital story to share with your students, and the knowledge and confidence to go forward. Frazel (2010, 2) enthuses, "Whether you are a novice or a seasoned technologist, you'll discover that there are many excellent websites to help you learn." For example, StoryKeepers Resources website (http://storykeepers.

wikispaces.com/), and Kathy Schrock's Guide to Everything: Digital Storytelling (http://www.schrockguide.net/digital-storytelling.html). I have also compiled a list of tech-related questions you should ask before introducing digital storytelling to your classroom (Table 3.3). If you can answer "yes" to every relevant question, I guarantee a much more successful experience. When the teacher is proactive about and prepared to tackle technical issues, the students can focus their efforts on learning.

Table 3.3. Digital storytelling technology checklist

General questions		
Does every student in my class have access to the same device (iPad, Chromebook, laptop, etc.) for making a digital story with?	□yes	□no
Can students take the device home (i.e. will students work on the digital stories both at school and at home)?	□yes	□no
Does every student have access to a digital camera, smartphone, or other such tool for taking photos and recording video?	□yes	□no
Can I help students transfer media between devices (e.g. a photo on a smartphone to the media library of a video editing program)?	□yes	□no
Does every student have access to a device for recording a voiceover (e.g. a smartphone with a built-in microphone, or laptop with an external microphone)?	□yes	□no
Are there private, quiet spaces around school where students can record their voiceovers?	□yes	□no
Does every student have a set of headphones for working on video editing?	□yes	□no
Questions for web-based video editing software users		
Is the internet connection in my classroom strong enough to support this project (i.e. can every student be online at the same time)?	□yes	□no
Are the network security settings compatible (e.g. will features of the editing software, such as pop-up windows, be allowed)?	□yes	□no
Questions for desktop video editing software users		
Is the software compatible with the device operating system (Windows, Mac, Linux, etc.)?	□yes	□no
Can the students initiate the software download, or does the device require an administrator password?	□yes	□no

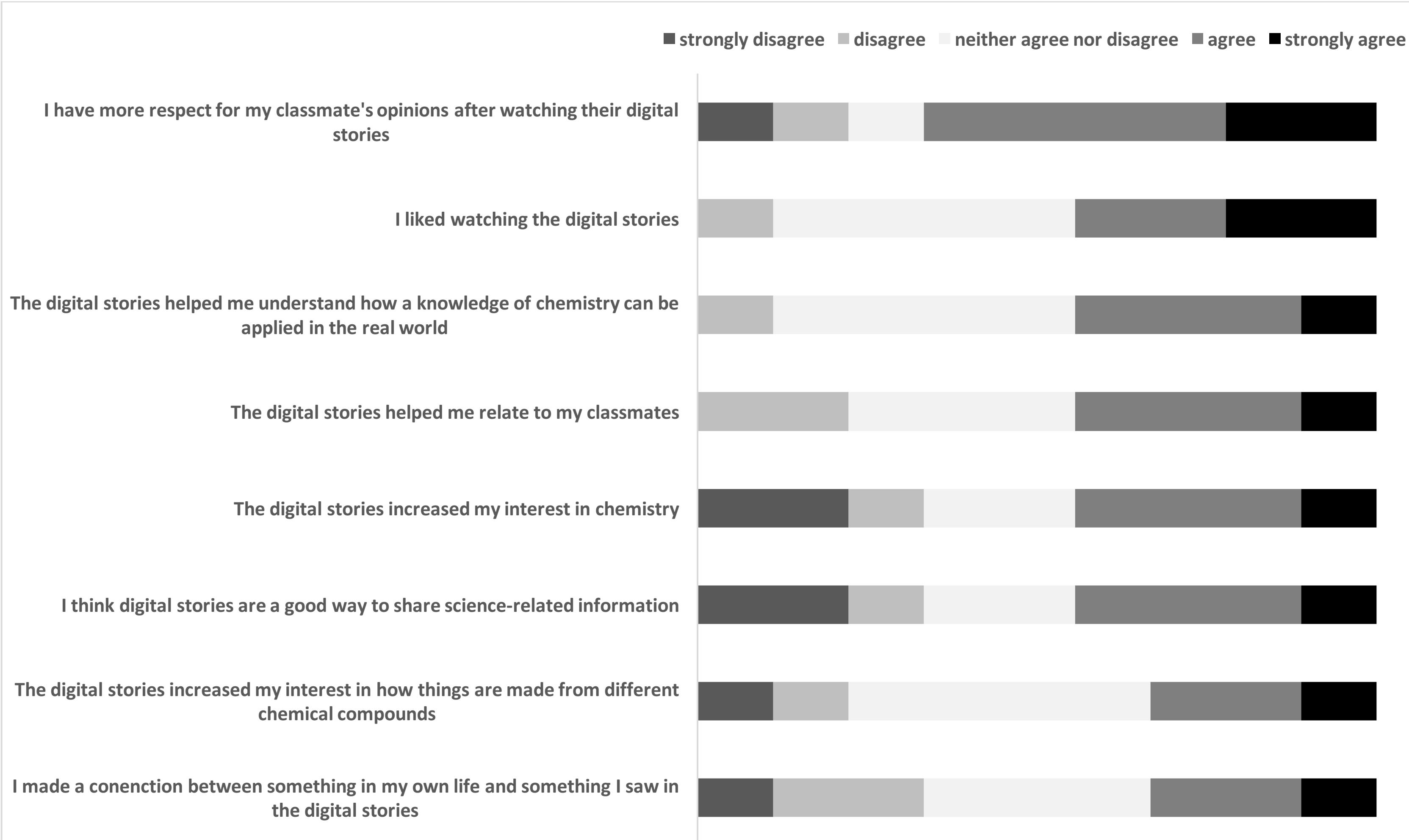

Figure 3.2. Survey results on watching digital stories in a chemistry class. Sample size is nine students. The shaded sections of each horizontal bar represent the percent of students that selected a particular response.

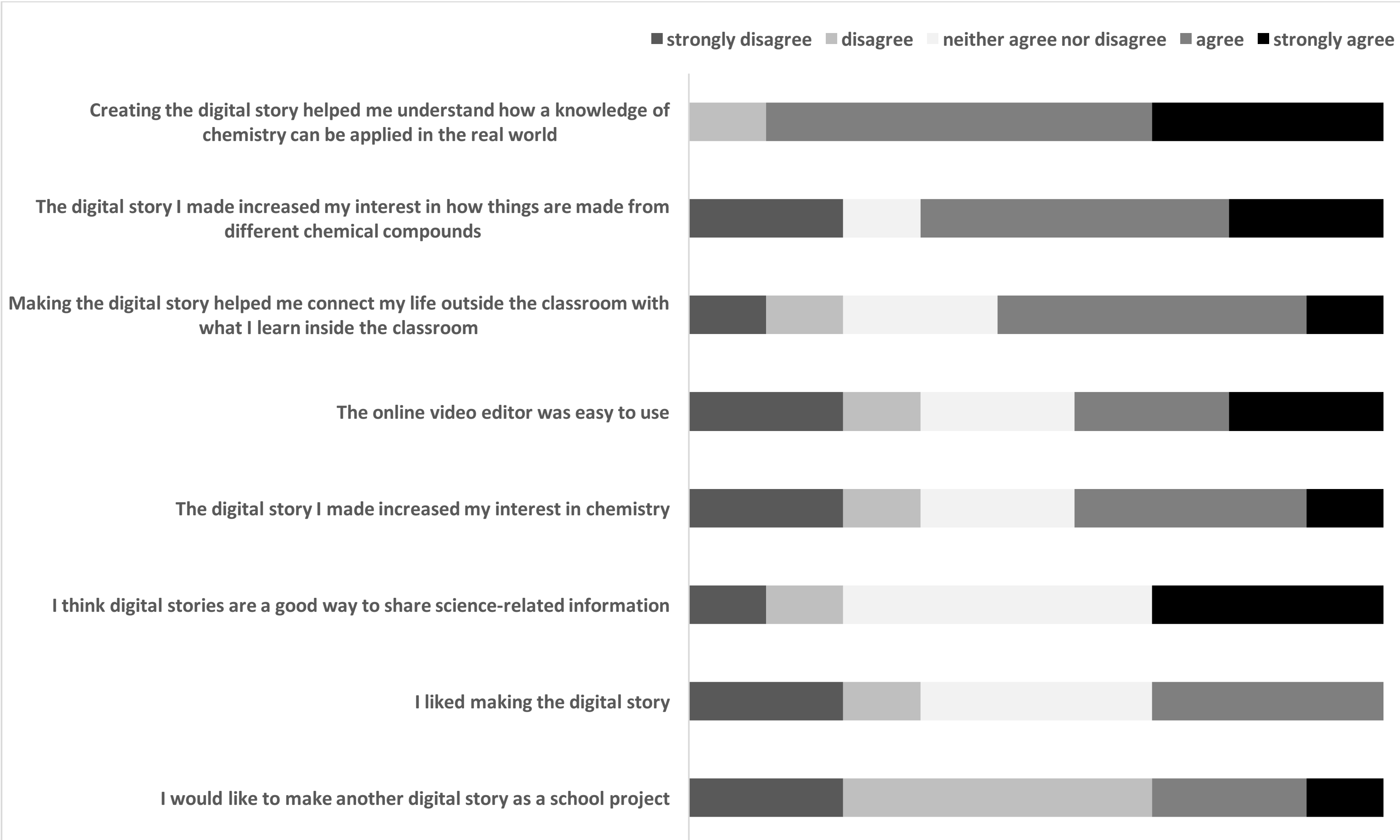

Figure 3.3. Survey results on making a digital story in a chemistry class. Sample size is nine students. The shaded sections of each horizontal bar represent the percent of students that selected a particular response.

Case Study 2: Middle School Earth Science

Project Overview

Teacher B wanted to integrate digital storytelling into her earth science class so that students would "take ownership of their learning," and have a more "meaningful and memorable" experience. We collaborated on a digital storytelling assignment for three different classes of middle school students. A tectonic plate boundary map (Figure 3.4), and a written prompt were used to initiate the activity:

> Prompt: Study the tectonic plate boundary map. Select a location on a plate boundary that you have either visited, plan to visit, or are personally interested in. Research the geologic history of that location. Makes notes about how tectonic activity in the area has impacted the human population (for example, an earthquake destroying homes or a mountain range providing recreational opportunities).

The middle school students responded with digital stories from around the globe. Although many of the stories were not intensely personal, they still reflected the individuality of each student by choice of location, choice of media, and sound of voice. Teacher B observed that "some of the students connected their stories to vacations," while others picked spots closer to home. She heard students discussing their locations with one another, making comments like, "Is that why these mountains are so rugged?" and, "Hawaii is not on a plate boundary. It is over a hotspot!" The survey statement, "I liked watching the digital stories" had a mean score as high as 4.5 (Figure 3.5). And regardless of the story focus, overall understanding of the theory of plate tectonics improved. Teacher B explained that her class had discussed plate boundaries prior to the digital storytelling activity, but that "students confused convergent and divergent as often as not." However, after the story making and sharing, "students could explain the two by themselves, with no apparent confusion." On the student survey, the statement "Creating the digital story helped me understand what happens at the different types of plate boundaries" received a high mean score of 4.2 (Figure 3.6). Students also agreed with the statement, "I think digital stories are a good way to share science-related information" (mean score of 3.9 on one survey and 4.1 on the other).

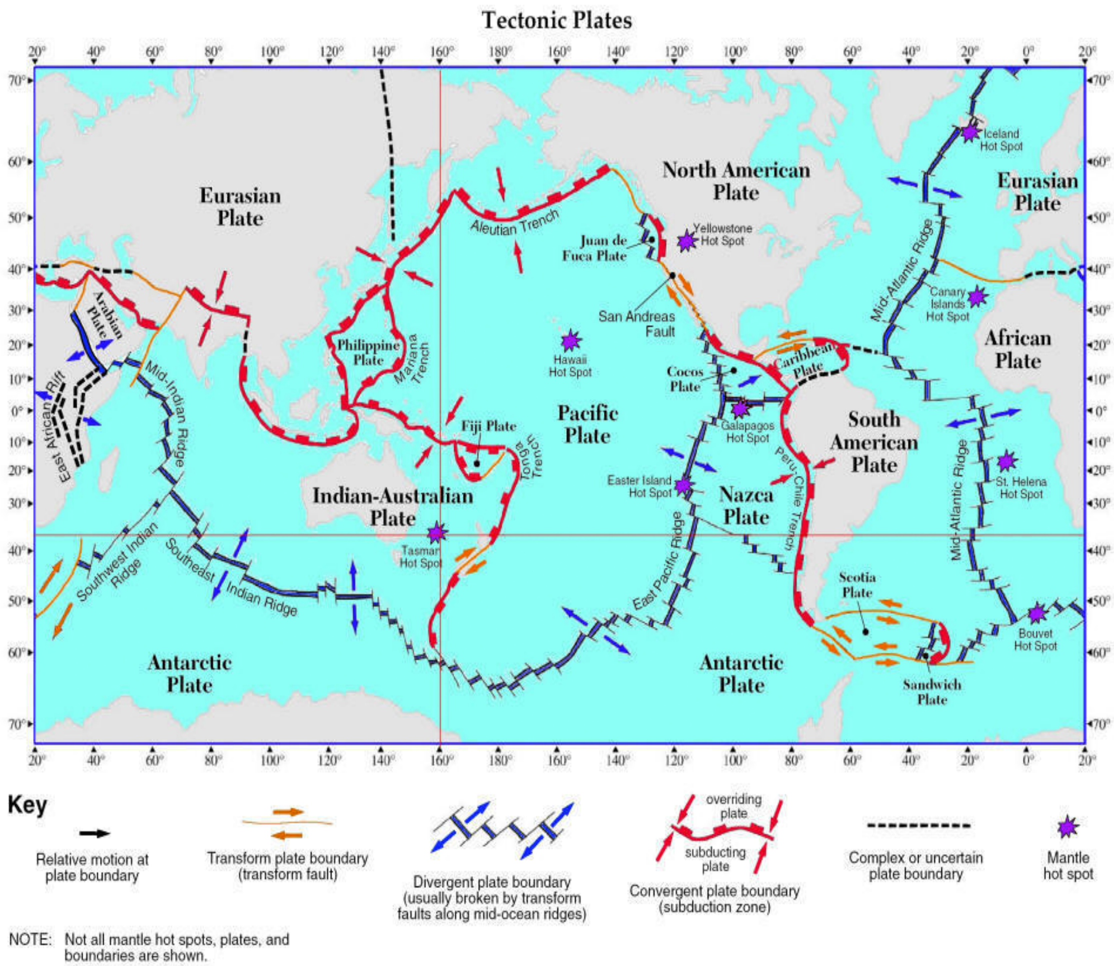

Figure 3.4. Tectonic plate boundary map. Image from Masters 2016.

Challenges

Teacher B encountered several problems as a result of the school's network security settings. Because WeVideo is a web-based software it was frequently blocked, and for more mysterious reasons, didn't operate consistently on every student's device (Nextbook

Tablets). Teacher B also reported that many students lost hours of work because the save function in WeVideo was unresponsive. Understandably, this caused a great deal of frustration: Only 32% of students agreed or strongly agreed with the statement, “I would like to make another digital story as a school project” (Figure 3.6). Furthermore, the students had difficulty conducting research using online search engines. Key terms such as geologic “hotspot” were flagged as inappropriate, and numerous websites were blocked for inexplicable reasons. Teacher B remarked that she would use digital storytelling again in her classroom, but only “if we can get our internet problems solved.”

The demographic of the middle school contributed to other issues. First, many of the students were from rural communities where technology wasn’t commonplace, or were simply too young to have acquired experience with online environments and complicated software. The student survey question, “The online video editor was easy to use,” received a low mean score of 2.2 (Figure 3.6). Trouble with WeVideo resulted in digital stories of questionable quality. Indeed, almost half of the students that created a story declined to share it with their classmates; participation in the survey about watching digital stories was similarly low. Overall, there was a definite lack of pride and confidence. This was particularly unfortunate because the stories that were shared publicly were enjoyed (Figure 3.5). Teacher B was the only individual with permission to view all the digital stories.

Solutions

Like any other tool, digital storytelling has its limitations; when used ineffectively, it can actually be detrimental to learning. Thus, McDrury and Alterio (2003, 83) designed a set of questions to help educators determine whether storytelling is the most suitable tool to teach a particular topic or aspect of the curriculum. The most relevant questions from their list are:

1. Is [digital] storytelling the most compelling and memorable way for this group of students to learn about this topic, and if so, why?
2. What outcomes do we want this group of students to achieve?
3. Will these outcomes be assessed, and if so, how?
4. How long will this [digital] storytelling activity take to design and implement?
5. What forms of support are required for students and educators involved in the activity?

The last question about support is particularly important in terms of the "digital" aspect of digital storytelling. As Teacher B discovered, technical issues can quickly lead to frustration and student resistance. A successful digital storytelling experience will probably require collaboration with the school's IT department or technical support person. You should also assess the user experience of your students. How prevalent is technology in their everyday lives? Can students troubleshoot problems on their own? A digital storytelling project is obviously too advanced for a kindergarten class, but the grade level at which it becomes an appropriate challenge is context dependent; you, as the teacher, must make this assessment. If technology is the metaphorical last straw—what determines whether you use digital storytelling or not—end your first project at the storyboard stage. This limits repetition and exposure to the science topic, multimedia training, and opportunities for feedback and discussion; however, it may be the best first step for a tech-wary instructor.

McDrury and Alterio (2003, 38) warn that "stories told in isolation and not reflectively processed are unlikely to lead to insight or result in meaningful learning." The act of sharing a digital story is just as important as making it. I was concerned that the middle school students were reluctant to show their stories to peers; however, I wasn't altogether surprised. Peer review was encouraged during the digital storytelling process, but never formally organized or structured. Without direction, students made little effort to solicit feedback. The completed digital stories thus contained personal information and ideas that had never been seen before. Vulnerability ruled and students shut down. To combat this behaviour, I suggest making feedback or evaluation forms a mandatory part of the digital storytelling project. For instance, before students transition to the video editor, require them to submit a storyboard with written feedback from three different classmates.

I also recommend an open class discussion. Explain that digital storytelling involves stages of reflection and evaluation that may feel uncomfortable; however, this discomfort is normal and actually helpful to the learning process. Remind students that "the stories [we] tend to find appealing and want to tell, or listen to, are often those that connect in some way with [our] own experiences" (McDrury and Alterio 2003, 47). A single digital story can elicit praise, criticism, or apathy, depending on the viewer. This is to be expected. The main purpose of sharing a digital story is not to entertain; it is to increase understanding, both of ideas and of people. McDrury and Alterio (2003, 61-84) describe strategies for building a classroom "storytelling culture" that will help students feel more comfortable in the role of a storyteller. For example, create a science-related sentence starter for a group writing activity. The starter gets passed from student to student, and each person writes a sentence, building on what was previously written. Together, the group creates a short story that is then presented to the class.

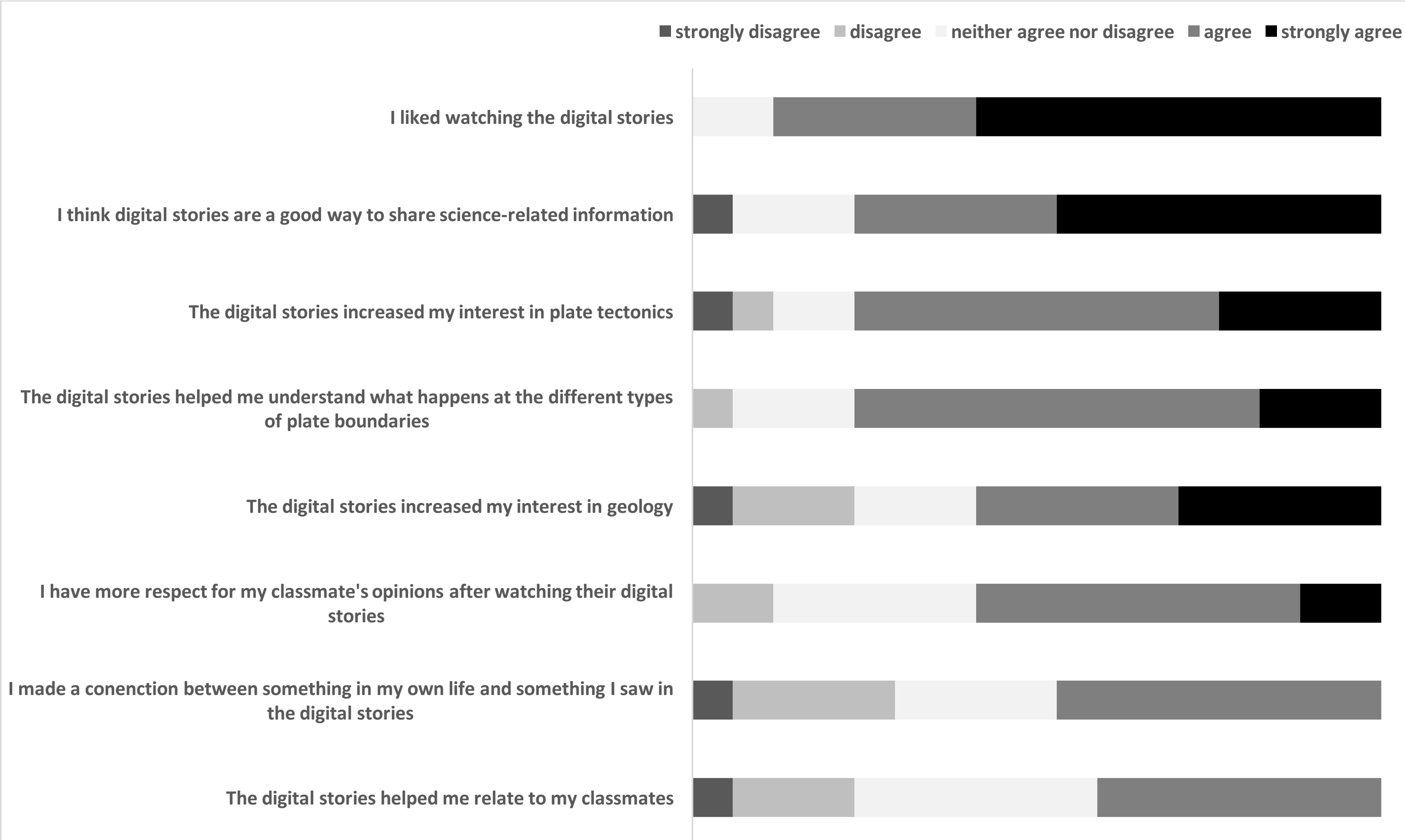

Figure 3.5. Survey results on watching digital stories in an earth science class. Sample size is seventeen students. The shaded sections of each horizontal bar represent the percent of students that selected a particular response.

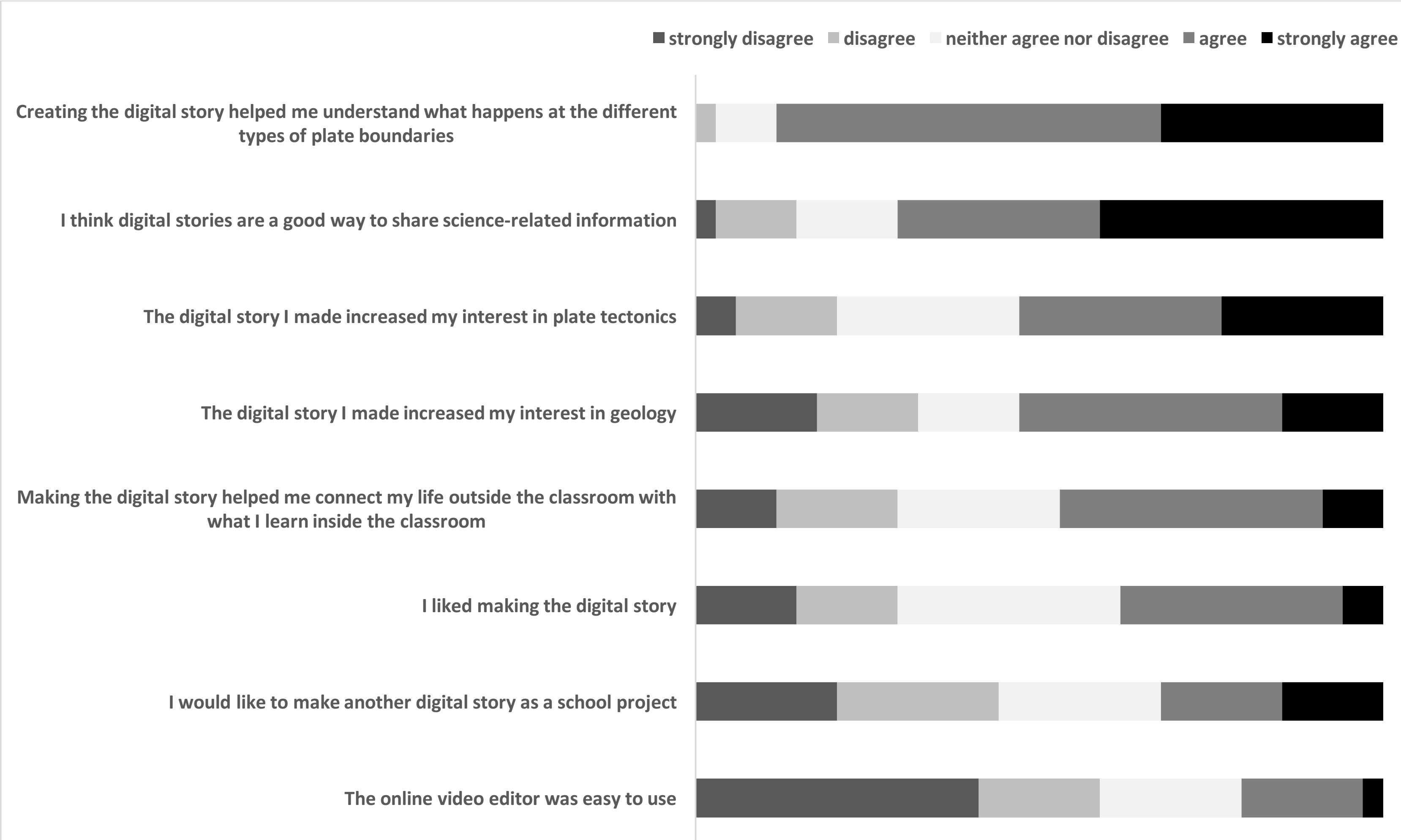

Figure 3.6. Survey results on making a digital story in an earth science class. Sample size is thirty-four students. The shaded sections of each horizontal bar represent the percent of students that selected a particular response.

Case Study 3: Middle School General Science

Project Overview

Teacher C used digital storytelling to introduce a unit on renewable energy in two general science classes. She organized each class into a large circle and initiated a discussion about the types of activities students' like to engage in after school and on the weekends. While many responded with "play video games" or "watch a show on television," the majority actually referenced outdoor recreation, such as "skiing at the local hill," "fishing with my Dad," or "hiking and camping." Teacher C asked students to pick one activity that they hoped to continue doing for many more years. The prompt for the digital storytelling project was as follows:

1. In order to keep doing your favourite activity, what does Idaho need to look like in twenty years? Draw pictures, or collect photos that depict your vision.
2. What renewable energy source will help make your vision possible? In what ways is that energy source different from non-renewable energy sources such as coal?

The prompt makes the most sense in light of the lesson Teacher C delivered during the previous class period: an explanation of climate change, and the associated challenges that society faces at both a local and global scale. The digital storytelling project required students to think more deeply and personally about these issues. Teacher C described how "getting middle schoolers to care about their future surroundings in 20 years is tough;" using digital storytelling, instead of a more traditional project or assignment, incorporated an element of "cool" that motivated the students.

Both iPads and Chromebooks were used to create the digital stories. Because of a limited number of devices, Teacher C paired classmates with a similar vision for the future of Idaho and they worked together on a group story. The classroom was almost overwhelmed with conversation and the exchange of ideas. Teacher C noted that, "The act of making a video kept [the students] interested for days, whereas if I had just asked them to…write a paper it would have been a few minutes." In contrast to the middle school earth science students, this group of students was much more "tech savvy" and could navigate WeVideo with minimal assistance. The survey statement "The online video editor was easy to use" received a mean score of 3.7 (Figure 3.7), and overall success with the technology promoted a positive learning environment. The vast majority of students liked making the digital story, and over 70% agreed or strongly agreed with the statement "Creating the digital story helped me understand how the use of energy resources will impact my future" (Figure 3.7).

I noticed a second contrast between this group of students and the middle school earth science classes: a willingness to share personal stories. In fact, viewing each other's digital stories really brought the general science class together. Students applauded after each showing and made remarks to their peers. Individual personalities came to light. For example, a fast-paced story about rising temperatures and the loss of a consistent snowpack showed one student at the local ski hill, launching off a jump into deep powder. Another student's ode to solar power featured beautiful photos from a family camping trip, and one particularly emotional story about a rusty boat and a father and son relationship integrated the natural sounds of a river. The survey statement "I liked watching the digital stories" received a high mean score of 4.1 (Figure 3.8). Teacher C praised the digital storytelling project because "nobody was left out," and "so often in science, the way students are assessed is by taking tests. This was an assignment that allowed everybody to have success, and some of the more successful students were the ones who are not the most academically gifted."

Challenges

The group story making, and what Teacher C called the “talkative” and “goofy” nature of her students, contributed to a loud and exciting learning environment. While this in itself was not a bad thing, it did present challenges for classroom management. For example, in order to record a clear voiceover without background noise, groups had to disperse throughout the school. By the end of the day, this confusion resulted in the loss of two pieces of expensive equipment. It was also difficult to keep students on task. For instance, one group’s promising discussion about solar panels somehow devolved into a heated debate about a new video game, while another group wasted a substantial amount of time selecting a soundtrack rather than focusing on the science content of their story. Overall though, the digital storytelling project was a success.

Solutions

In regards to classroom management, there are different ways to structure a digital storytelling project to help keep students on track. Ohler (2006) recommends prioritizing the planning and story mapping stages over the digitizing and video editing stages. He says, “Writing is key. Even though students’ final products are media-based, the most important tool used in the creation of a digital story is writing scripts” (Ohler 2006, 46). Ask students to create a story map—a “one-page diagram showing how the essential components of a story are incorporated into the overall flow of the narrative” (Ohler 2006, 45)—so you can quickly assess the strengths and weaknesses of a story while it’s still in the planning stage. I suggest sharing Zak’s (2015) video with students as well (about the father and terminally ill son); it introduces Freytag’s classic “dramatic story arc,” and demonstrates the influence that a good story can have on the brain. If you’re feeling overwhelmed, think about collaborating with another teacher at your school. For instance, an English teacher might take on the script writing as a student assignment because it is an opportunity to practice writing in a particular style and to a specific audience. Likewise, a communications or media teacher might be interested in making the video editing and production stage part of their course. But whether you collaborate or not, a digital storytelling project will be more manageable if presented as a series of smaller objectives (Figure 3.9).

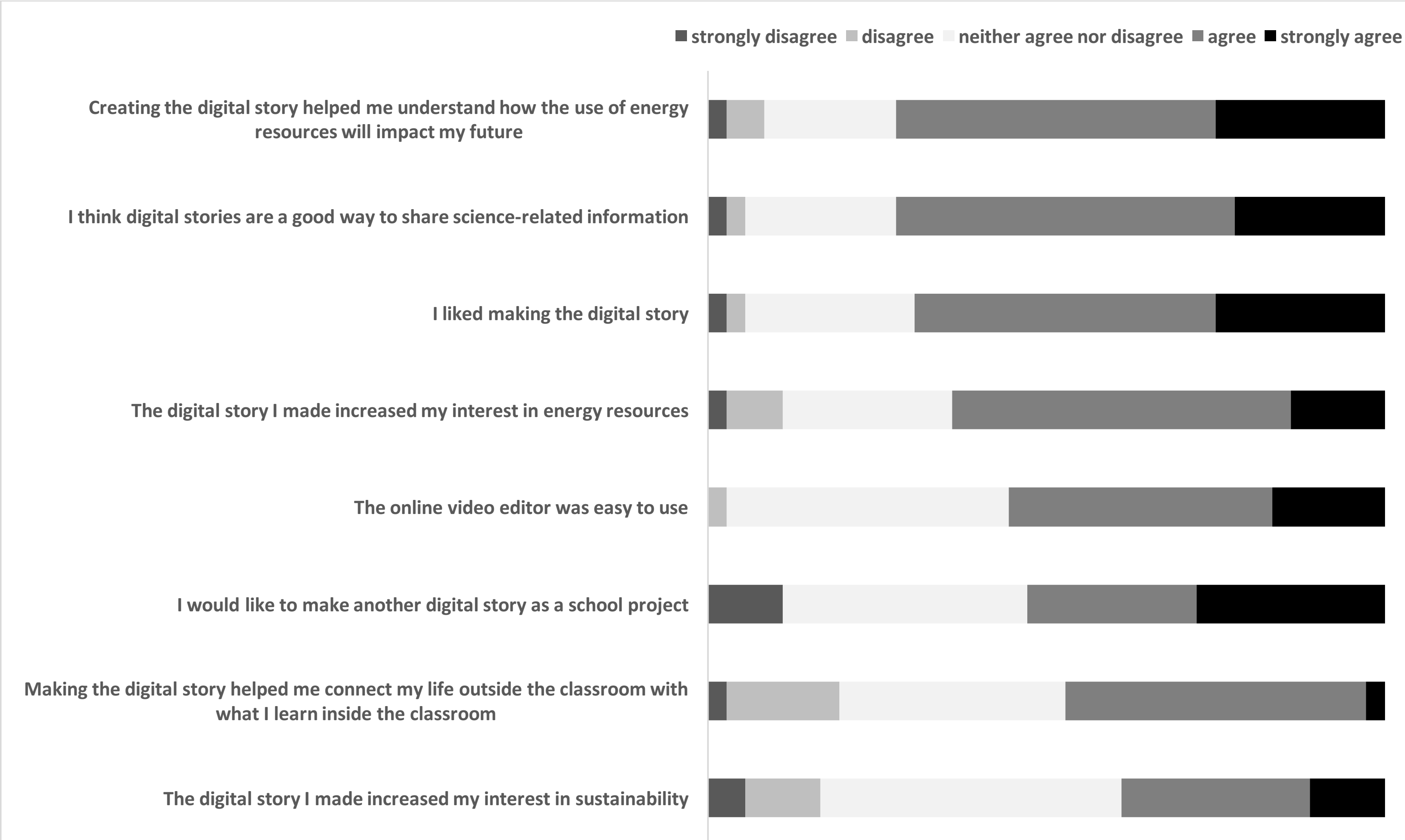

Figure 3.7. Survey results on making a digital story in a general science class. Sample size is thirty-six students. The shaded sections of each horizontal bar represent the percent of students that selected a particular response.

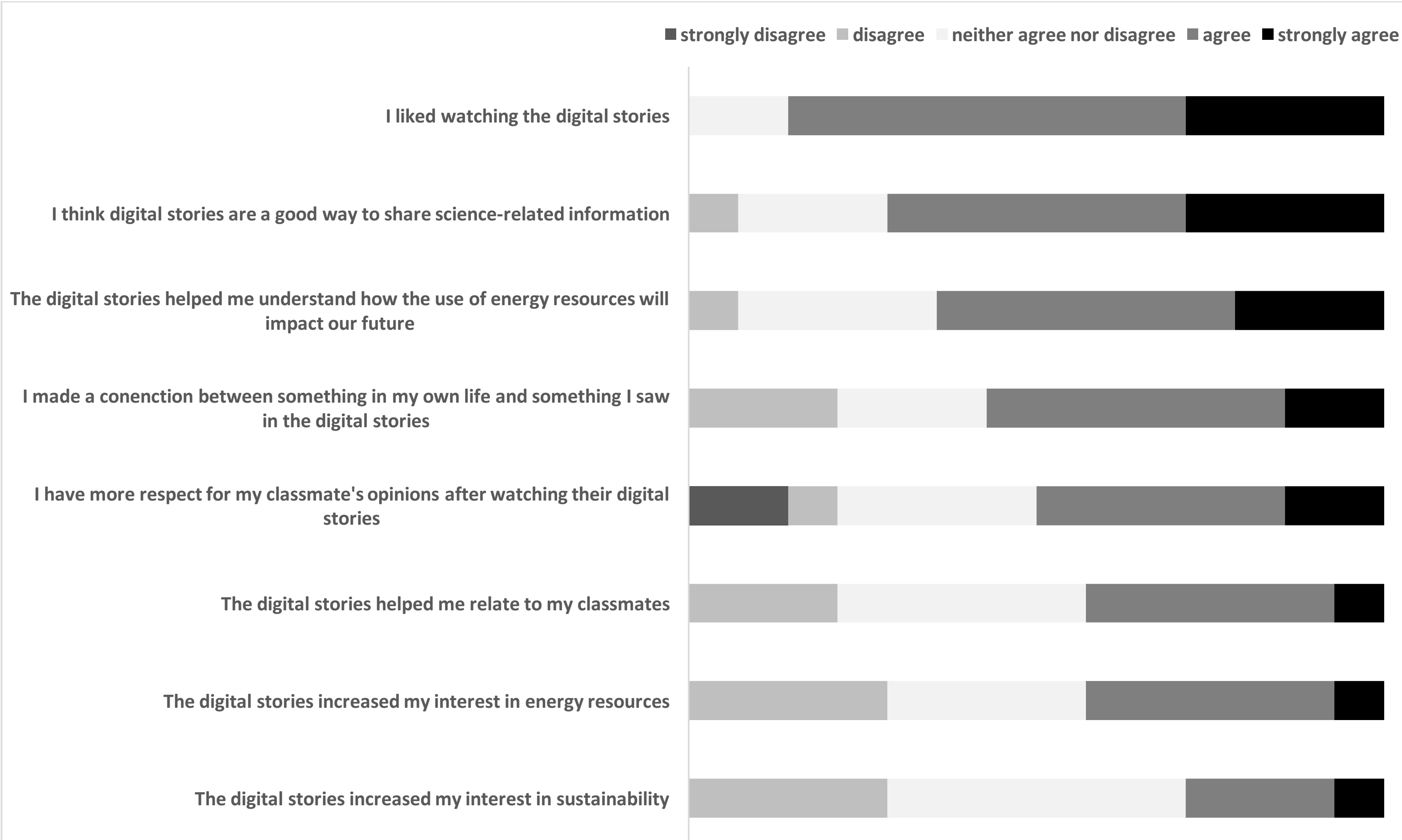

Figure 3.8. Survey results on watching digital stories in a general science class. Sample size is fourteen students. The shaded sections of each horizontal bar represent the percent of students that selected a particular response.

PLANNING

1) Write a response to the prompt.

2) Brainstorm how your response can be crafted into a story. Is there a problem or conflict that needs to be resolved?

3) Draw a story map and submit it to the teacher for feedback.

4) Write the first draft of your script.

5) Read your script to at least two classmates. Make revisions based on the feedback you receive.

PREPARING

1) Record your voiceover.

2) Obtain a storyboard template and transfer your script onto it.

3) Look for relevant photos, images, video, sounds, and music. All media must be saved as a digital file.

4) Build your storyboard, searching for additional media as needed.

5) Share your storyboard with two classmates. Make changes based on the feedback you receive.

PRODUCING

1) Import all your media into the video editor.

2) Starting with the voiceover, arrange each element in the timeline.

3) Add effects.

4) Show a preview of your digital story to a classmate. Make changes based on the feedback you receive.

5) Save and export your digital story.

6) Share with the class.

Figure 3.9. A deconstruction of the digital storytelling process. There are three main stages, each with its own set of objectives.

Case Study 4: High School Geology

Project Overview

Of all the teachers, Teacher D had the most success with her digital storytelling project; this was due in part to my increased preparedness as a facilitator. From earlier experiences with Teachers A, B, and C, I knew which problems were likely to surface, and also how to be proactive. It also helped that Teacher D chose an ideal context for integrating digital storytelling: a final project for a high school geology class of five senior students. She carried out a trial run with the WeVideo software on a school computer, and worked with the technology support person to solve a few minor issues. The digital storytelling project was introduced at the beginning of the semester. Class time wasn't allocated until later, but students had more opportunities to think about the project, propose their ideas, and start writing.

> Prompt: "The national parks have been woven into the fabric of American life for so many generations that it's hard to imagine the nation without them. The parks were born because in the mid-1800s a relatively small group of people had a vision—what writer Wallace Stegner has called "the best idea we ever had"—to make sure that America's greatest natural treasures would belong to everyone and remain preserved forever."
> *National Geographic. U.S. National Parks-In the Beginning. Published May 26, 2010. Accessed on February 2, 2017 at http://www.nationalgeographic.com/travel/national-parks/early-history/*
>
> Instructions:
> 1. Select a National Park that you have visited in the past. If you haven't had this privilege, select one that you would like to visit in the future.
> 2. Research the geologic history of your chosen park. Below are examples of the types of questions you should explore:
>   -How did the movement of tectonic plates create different features on the landscape?
>   -When did different landscape features first start to form, and why?
>   -Are volcanoes or earthquakes a threat to visitors in the park?
> 3. Write a short story (less than 250 words) about the geologic history of your chosen park. The focus of the story should be geology, but you should also include details about your own connection to the park. Did you notice a particularly striking geologic feature when you visited? If you're planning a visit for the future, what attracted you to this one park over all the others?

4. Remember, this is not a formal report. Write your story in a conversational tone (as if you were telling it to a friend).

When Teacher D turned her full attention to the digital storytelling project, most students had already completed the first draft of their scrips. Classroom time was used effectively to share and edit scripts, and start storyboarding. From that point on, each student progressed through the digital storytelling process at their own pace; this was easy to manage because of the small class size.

Teacher D observed that her students "took pride in their productions and encouraged each other." The survey question "I liked watching the digital stories" received a high mean score of 4.8 (Figure 3.10). Students were "surprised by how nicely the videos flowed," and some even remarked that they "would use what someone else had done as a way to improve [my] own video." Teacher D was pleased with the work ethic exhibited by her students, and I was impressed by their willingness to collaborate. For example, after showing one student how to use WeVideo, my assistance was no longer required. That student passed his knowledge to another student, who in turn passed it to another, and so on throughout the class. The supportive learning environment contributed to all five of the students agreeing or strongly agreeing with the statement, "I have more respect for my classmate's opinions after watching their digital stories" (Figure 3.10).

According to Teacher D, digital storytelling "provides a way to delve deeper into certain topics." In this case, students explored geology from a personal perspective. All five of the students agreed or strongly agreed with the statement, "The digital story I made increased my interest in a National Park" (Figure 3.11). Teacher D noted that two students "'re-experienced' their trip to a national park through their digital product," and showed their appreciation for the natural world through comments about the "beauty of the landscapes." One student who made a story about Alcatraz not only learned that "the island wasn't just a place where a prison was built," but also "how the island itself came to be." The student survey question, "Creating the digital story helped me understand how past geologic forces can shape the landscape," received a mean score of 3.8 (Figure 3.11).

I have excluded a *Challenges* and *Solutions* section from this particular digital storytelling project because of a lack of useful information. There were no significant problems to be solved! Teacher D's only critique was that because it was a "time consuming project," she would avoid using digital storytelling in "core science classes overloaded with content." We discussed alternatives. In the upcoming semester, Teacher D plans to integrate digital storytelling into an environmental science class. She wants her students to "make personal connections with resources (land use, water availability, consumption, population demands, etc.)." Teacher D's consideration of an appropriate context for digital storytelling is exemplary, and also a major contributor to her success.

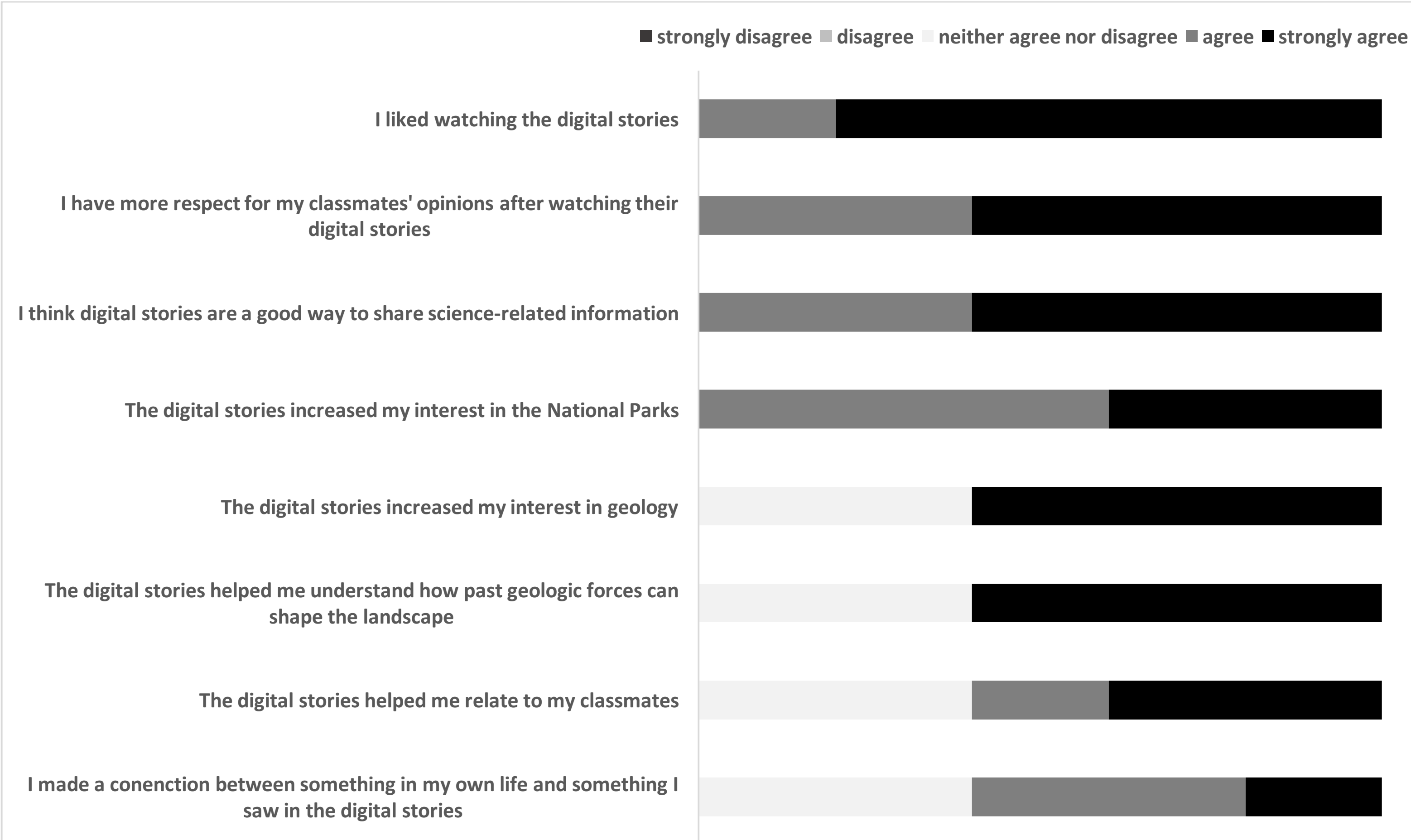

Figure 3.10. Survey results on watching digital stories in a geology class. Sample size is five students. The shaded sections of each horizontal bar represent the percent of students that selected a particular response.

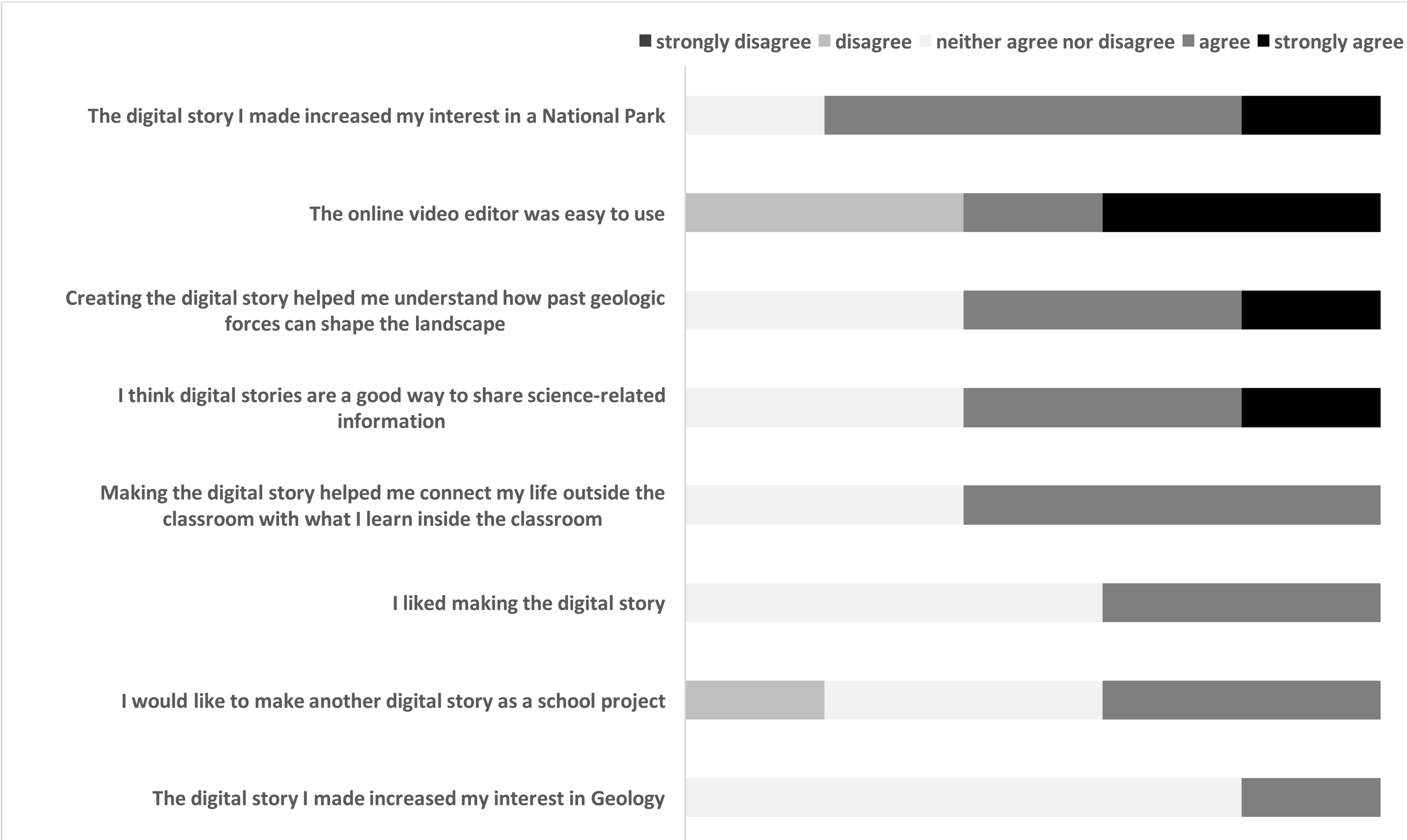

Figure 3.11. Survey results on making a digital story in a geology class. Sample size is five students. The shaded sections of each horizontal bar represent the percent of students that selected a particular response

Synthesis

A comparison of survey results from the four case studies revealed two interesting patterns: 1) statements with similar mean Likert scores across classes; and 2) statements with significantly different mean Likert scores between classes. For the survey statements related to making a digital story (Figure 3.12), the class scores did not differ significantly for 5 of the 8 statements. For the survey statements related to watching digital stories (Figure 3.13), the class scores did not differ significantly for 6 of the 8 statements. These data suggest that some aspects of the digital storytelling project were consistent, regardless of the context. I think it is reasonable to conclude that digital storytelling can increase student interest in, and understanding of, course content, help students make connections with life outside the classroom, and build rapport between classmates. These benefits are available to all teachers. As Frazel (2010, 2) notes, “Digital storytelling is applicable across the curriculum, at all grade levels, and for the distributed learning population in every school.”

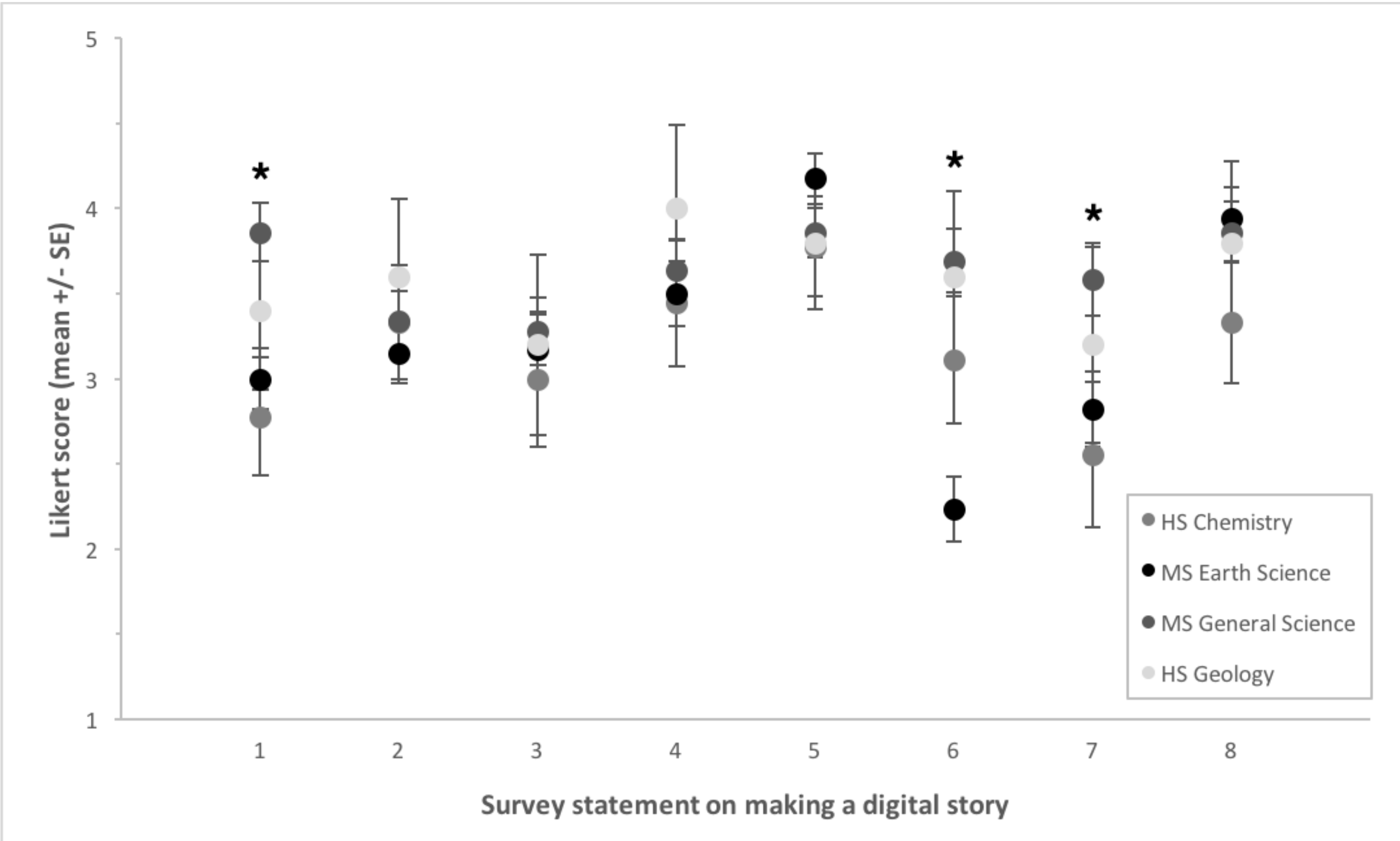

Figure 3.12. A comparison of mean Likert scores between four different classes. Survey statements relate to student attitudes about making digital stories. * indicates a significant difference. For exemplar survey statements, see Appendix F.

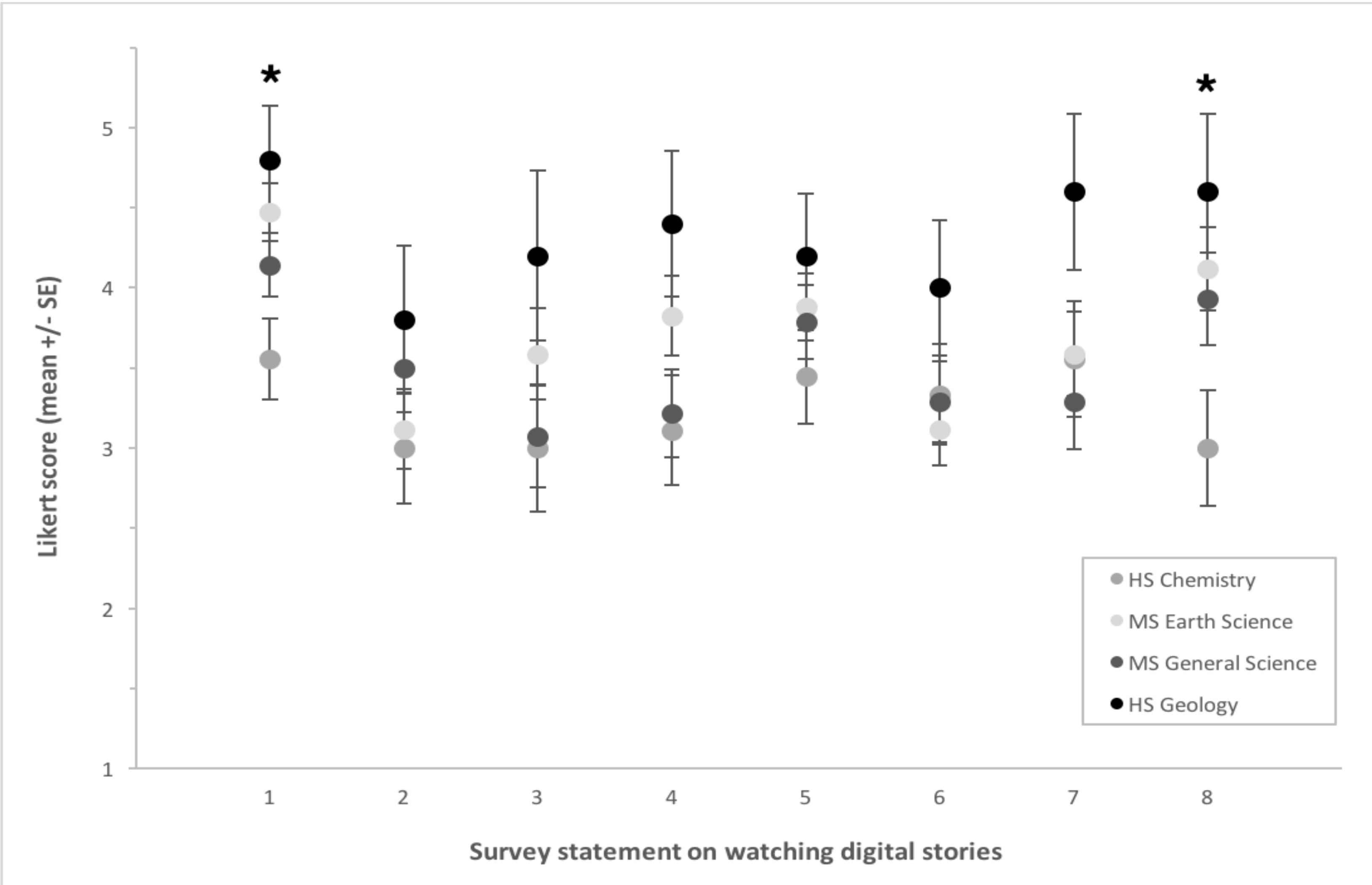

Figure 3.13. A comparison of mean Likert scores between four different classes. Survey statements explore student attitudes about watching digital stories. * indicates a significant difference. For exemplar survey statements, see Appendix F.

Significant differences between mean class responses to survey statements are also informative, and confirm what was presented earlier in the *Challenges* section of each case study. When student attitudes about making digital stories were considered, three survey statements showed a significant effect of class on mean Likert score (Figure 3.12): "I liked making the digital story" ($F=5.05$, $df=3$, $p=0.0029$); "The online video editor was easy to use" ($F=10.22$, $df=3$, $p=0.0001$); and "I would like to make another digital story as a school project" ($F=2.73$, $df=3$, $p=0.0495$). For statement 1, "I liked making the digital story," post hoc tests comparing individual class means indicated significant differences between Middle School General Science and High School Chemistry ($p=0.0330$), and Middle School General Science and Middle School Earth Science ($p=0.0049$) (Table 3.4). For statement 6, "The online video editor was easy to use," post hoc tests comparing individual class means indicated a significant difference between Middle School General Science and Middle School Earth Science ($p=0.0001$) (Table 3.4). For statement 7, "I would like to make another digital story as a school project," post hoc tests did not reveal significant differences between specific classes (Table 3.4). All three survey statements with a significant effect of class were characterized by a range of mean Likert scores above, below, and equal to the neutral score of 3 (neither agree nor disagree).

Table 3.4. Mean Likert scores for survey statements on making a digital story

Class	Sample size	Statement 1	Statement 6	Statement 7
High School Chemistry	9	2.78	3.11	2.56
Middle School Earth Science	34	3.00	2.24	2.82
Middle School General Science	36	3.86	3.69	3.58
High School Geology	5	3.40	3.60	3.20

The data I collected suggests that students who experience technical problems with the online video editor do not enjoy making the digital story. Classroom observations and feedback from the teachers support this conclusion as well. I would argue that the ability of the teacher to facilitate a digital storytelling project, and effectively manage the technology, has a significant impact on success. Sadik's (2008, 501) study found that "teachers were not technically proficient in the use of Photo Story and other multimedia editing packages, and could not explain all the technical and organizational procedures to use the computer and other peripherals to produce digital stories." My advice to practitioners then, is to master the technology before introducing it to students. Refer back to Table 3.3, and ensure that you have completed the technology checklist. Carry out a trial run by making your own digital story with the equipment that your students have access to, and in the same classroom setting. The video you create can be played for students as an exemplar, or used as a primer to a new science unit. In the next chapter I will provide a more detailed guide to making a digital story.

When student attitudes about watching digital stories were considered, two statements showed a significant effect of class on mean Likert score (Figure 3.13): "I liked watching the digital stories" (F=4.05, df=3, p=0.0131); and "I think digital stories are a good way to share science-related information" (F=3.01, df=3, p=0.0409). For statement 1, "I liked watching the digital stories," post hoc tests comparing individual class means indicated a significant difference between High School Geology and High School Chemistry (p=0.0239), and Middle School Earth Science and High School Chemistry (p=0.0249) (Table 3.5). However, it should be noted that all mean Likert scores were above 3.5, indicating that all four classes agreed with the statement, even though they did so to varying degrees. For statement 8, "I think digital stories are a good way to share science-related information," post hoc tests did not reveal significant differences between specific classes (Table 3.5).

Table 3.5. Mean Likert scores for survey statements on watching digital stories

Class	Sample size	Statement 1	Statement 8
High School Chemistry	9	3.56	3.11
Middle School Earth Science	34	4.47	2.24
Middle School General Science	36	4.14	3.69
High School Geology	5	4.80	3.60

Overall, my research findings are similar to what has been reported in previous studies. For instance, Sadik (2008, 502) concluded that digital storytelling "enriched the classroom learning environment, the curriculum, and student learning experiences by providing an open-ended, creative and motivating productive tool in the classroom." And Hung, Hwang, and Huang (2012, 368) showed that digital storytelling could "enhance the students' science learning motivation, problem-solving competence, and learning achievement." However, I found it difficult to make generalizations across the case studies because the digital storytelling project goals were met to different degrees in each class. In addition, the results from my student surveys and teacher questionnaire need to be interpreted in the context of a few limitations. First, I did not thoroughly validate either evaluation instrument; therefore, the questions may not measure exactly what they were intended to. Second, I constrained the scope and detail of the student surveys to fit into the time allocated by teachers. A survey that took longer than ten minutes to administer and complete was not an option. Third, I had a limited sample to obtain feedback from (due to student enrolment and the number of teachers that volunteered to collaborate). These limitations could be easily addressed by future studies though.

Digital storytelling is no longer the unknown, esoteric educational tool that it once was. It has been successfully integrated into many different learning environments: higher education (France and Wakefield 2011; Suwardy, Pan, and Seow 2012); online courses (Mullet and Cain 2014); K-12 classrooms (Smeda, Dakich, and Sharda 2014); short workshops (Daskolia, Kynigos, and Makri 2015); and adult education (Rossiter and Garcia 2010), to name a few. Although there is now a strong precedent for using digital stories in the classroom, the humanities wield the hammer more frequently than the sciences. But this should not deter capable science teachers. The information presented at the beginning of this chapter, and the data gathered from the classroom case studies, are intended as evidence and encouragement. Digital storytelling meets educational standards, fits with our understanding of how learning takes place, and brings additional benefits to the classroom, such as student engagement and technology training. I recommend that first-time users initiate digital storytelling projects only after thorough preparation, and consideration of a suitable context. Select a small class of tech savvy students, and a science topic with a complexity that is better understood through multiple perspectives. Through continued practice, a storytelling approach can become integral to your teaching; a conventional way for your students to learn about and communicate science.

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Appendix C: Instructional Materials

DIGITAL STORYTELLING PROJECT

Learning Goals
By completing this assignment, students will…
1) Understand how plate tectonics shape the landscape.
2) Practice using and explaining geology terminology.
3) Learn about the geologic history of National Parks.
4) Improve their communication skills in different mediums.

Prompt: "The national parks have been woven into the fabric of American life for so many generations that it's hard to imagine the nation without them. The parks were born because in the mid-1800s a relatively small group of people had a vision—what writer Wallace Stegner has called "the best idea we ever had"—to make sure that America's greatest natural treasures would belong to everyone and remain preserved forever."
National Geographic. U.S. National Parks-In the Beginning. Published May 26, 2010. Accessed on February 2, 2017 at http://www.nationalgeographic.com/travel/national-parks/early-history/

Instructions:
1. Select a National Park that you have visited in the past. If you haven't had this privilege, select one that you would like to visit in the future.
2. Research the geologic history of your chosen park. Below are examples of the types of questions you should find answers to:
    - -How did the movement of tectonic plates create different features on the landscape?
    - -When did different landscape features first start to form, and why?
    - -Are volcanoes or earthquakes a threat to visitors in the park?
3. Write a short story (less than 250 words) about the geologic history of your chosen park. The focus of the story should be geology, but you should also include details about your own connection to the park. Did you notice a particularly striking geologic feature when you visited? If you're planning a visit for the future, what attracted you to this one park over all the others?
4. Remember, this is not a formal report. Write your story in a conversational tone (as if you were telling it to a friend).
5. Share your story with another student **by reading it aloud to them**. Ask for feedback and make changes if necessary.
    - -Does the story transition well from one idea to the next?
    - -Are the geology concepts well explained?
    - -Do you speak in an engaging voice, and slow enough to understand?
5. Collect photographs, images, sounds, and videos to support your story. **Put all of your media together in a folder on the computer.** Below are examples of the type of media you could collect:
    - -a photograph of you hiking with the Teton Mountains in the background (JPEG file)
    - -a sound clip of a volcano eruption (MP3 file)
    - -a video clip of you moving pieces of cardboard together to demonstrate the movement of plates (MP4 file)
    - -a sketch you made of the different rock layers in a canyon (JPEG file)
6. Make a storyboard to plan out how your media and your script will fit together.

Figure A.1. Digital storytelling assignment. Adapted to a high school geology course.

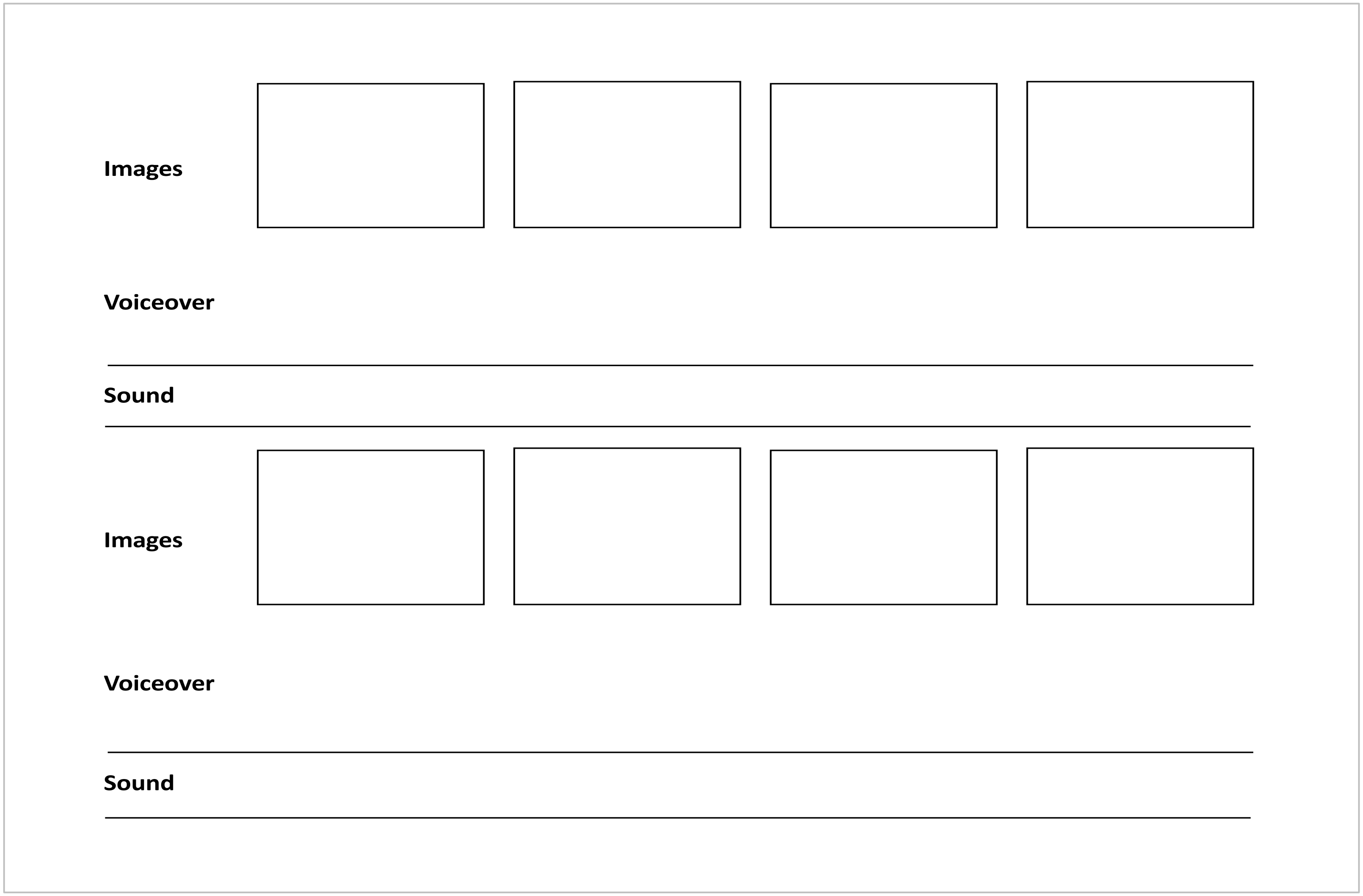

Figure A.2. Storyboard template.

Level	**3**	**2**	**1**
Scientific concept Is the information correct?	All of the information is correct	Most of the information is correct	Some of the information is correct
Scientific concept Is the information easy to understand?	The concept is explained in a clear and concise manner	Some aspects of the concept are confusing	The concept is hard to understand
Human element Is there a connection between science and society?	It is clear how/why the science concept is important to society	Some effort is made to explain how/why the science concept is important to society	No connection is made between the science concept and society
Human element Does the narrator have an opinion?	The narrator's perspective or personal experience is evident	The narrator's perspective is hard to define	The narrative is completely objective and monotone
Communication Is the story engaging?	The story elicits a strong emotional response	Some moments in the story elicit an emotional response	The story is watchable
Communication Do the images and/or video and soundtrack contribute to the story?	Images and/or video and soundtrack contribute to the mood, tone, and pace of the story	Images and/or video and soundtrack match the narrative	Images and/or video and soundtrack do not match the narrative and detract from the story

Figure A.3. A simple digital story rubric.

Table A.1. A detailed digital story rubric adapted to a high school chemistry course

Category	Excellent (3 pts)	Good (2 pts)	Satisfactory (1 pt)
Questions	-answers to both questions are clear and detailed	-answers to both questions are clear	-both questions are answered
Scientific Content *double points	-3 different objects -6 chemical compounds are identified by name and formula	-3 different objects -4 chemical compounds are identified by name and formula	-3 different objects -3 chemical compounds are identified by name and formula
Scientific Accuracy *double points	-names and formulas for all compounds are correct -all compounds are reduced to the correct elements -all sources of information properly cited in the credits	-names and formulas for most compounds are correct -most compounds are reduced to the correct elements -all sources of information properly cited in the credits	-names and formulas for most compounds are correct -most compounds are reduced to the correct elements -all sources of information cited in the credits
Human element	-story is unique and specific to the narrator -audience learns something personal about the narrator -audience connects to the narrator	-story is specific to the narrator -audience learns something personal about the narrator	-story is specific to the narrator
Visuals -photographs, images, video clips	-visuals are originals, or legally obtained copies -visuals match the tone and content of the voiceover -visuals help the audience understand the answer to the question	-visuals are originals, or legally obtained copies -visuals match the tone and content of the voiceover	-visuals are originals, or legally obtained copies
Voiceover	-voiceover is clear and audible -speaker makes good use of pauses and changes of pace -speaker is expressive and engaging	–voiceover is clear and audible -speaker uses some pauses and/or changes of pace -speaker is expressive	-voiceover is audible -speaker is monotone
Soundtrack	-music and/or sounds add emotion to the story -music and/or sounds complement the voiceover	-music and/or sounds complement the voiceover	-music and/or sounds sometimes interfere with the voiceover
Formatting	-video has a unique title -video has end credits -the length of the video is between 2 and 5 minutes	-video has a title -length of the video is between 2 and 5 minutes	-video has a title -video is shorter than 2 minutes or longer than 5 minutes

Appendix D: Evaluation Instruments

Teacher Questionnaire

Please write/type detailed responses to the questions below:

Why did you decide to use digital storytelling in your classroom?

What question or topic did your students make a digital story about?

Did making the digital story improve your students' understanding of the question or topic? Provide specific evidence to support your answer.

Did making the digital story increase your students' interest in the question or topic? Provide specific evidence to support your answer.

Do you think that making the digital story helped your students connect their personal lives with the question or topic? Please explain.

Do you think that watching the digital stories helped your students connect with their fellow classmates? Please explain.

What proportion of your students benefitted from the digital storytelling project?

Do you think that digital storytelling is an effective way for students to learn about science?

Will you use digital storytelling again in your classroom? Explain why or why not.

Figure A.4. Adaptation of the original teacher questionnaire. The space for each response was limited to condense the questions onto one page.

Student Survey

What is your gender identity?

- ○ Male
- ○ Female
- ○ Other: ______________________

What grade are you in?

- ○ 3-5
- ○ 6-8
- ○ 9-12

For each of the questions below, circle the response that best describes how you feel about the statement.

	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
1. I liked making the digital story.	1	2	3	4	5
2. Making the digital story helped me connect my life outside the classroom with what I learn inside the classroom.	1	2	3	4	5
3. The digital story I made increased my interest in Chemistry.	1	2	3	4	5
4. The digital story I made increased my interest in how things are made from different chemical compounds.	1	2	3	4	5
5. Creating the digital story helped me understand how a knowledge of chemistry can be applied in the real world.	1	2	3	4	5
6. The online video editor was easy to use.	1	2	3	4	5
7. I would like to make another digital story as a school project.	1	2	3	4	5
8. I think digital stories are a good way to share science-related information.	1	2	3	4	5

Figure A.5. Student survey on making a digital story. Adapted to a high school chemistry class.

Student Survey

What is your gender identity?

- O Male
- O Female
- O Other: ______________________

What grade are you in?

- O 3-5
- O 6-8
- O 9-12

For each of the questions below, circle the response that best describes how you feel about the statement.

	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
1. I liked watching the digital stories.	1	2	3	4	5
2. I made a connection between something in my own life and something that I saw in the digital stories.	1	2	3	4	5
3. The digital stories increased my interest in Geology.	1	2	3	4	5
4. The digital stories increased my interest in plate tectonics.	1	2	3	4	5
5. The digital stories helped me understand what happens at the different types of plate boundaries.	1	2	3	4	5
6. The digital stories helped me relate to my classmates.	1	2	3	4	5
7. I have more respect for my classmate's opinions after watching their digital stories.	1	2	3	4	5
8. I think digital stories are a good way to share science-related information.	1	2	3	4	5

Figure A.6. Student survey on watching digital stories. Adapted to a high school chemistry class.

Chapter IV

How to Tell Your Story

"Storytelling is the most powerful way to put ideas into the world today."
–Robert McKee

As stated in the preface, my goal for this dissertation was to convince readers that digital storytelling is a useful endeavour; one worth setting aside other priorities to engage with and practice. I provided ample evidence that supports the use of digital storytelling in science communication and education, referring both to a wide range of published sources, and to my own classroom studies. In the final chapter I transition from talking about *why* you should tell digital stories, to talking about *how.* I have created a digital story recipe by taking what I learned at a StoryCenter workshop (Lambert et al. 2010), and combining it with my own unique perspective as a scientist and educator. Although the recipe was created with the appetites of scientists in mind, it can be further modified to satisfy individual tastes.

The Recipe

Ingredients

1) The script

This is the backbone of the story. It should be a concise (less than 250 words), and focused piece of writing. What is the main message you are trying to convey? Interview questions on the Nobel Prize Inspiration Initiative website can serve as writing prompts (http://www.nobelprizeii.org/). For example, "Why did you want to become a scientist?" or "Who inspired you as a student?" or "Have you ever had to give up on an experiment?"

Completing the script will require self-reflection and multiple drafts. Write in the first person point of view. Be genuine. This is not a formal piece of writing for a journal; emotion and personality are central to the script. Think carefully about the audience you are addressing, and continue to ask: How does this story show who I am?

Olson (2015, 16) has developed a simple template for effective storytelling: ______and______, but______, therefore______. For example: This is a story about a little girl who loved to climb mountains. *And*, every time she climbed a mountain she saw a pika. In fact, she spent so much time scrambling amongst the rocks with the pika that she decided she wanted to be one when she grew up. *But*, she soon realized that this was an unrealistic dream. *Therefore,* the little girl decided to become a scientist who studies pika instead. As Olson (2015, 98) explains, "The word *but* introduces what is often called the 'inciting incident,' which is where the story begins." Olson's (2015, 16) template steers away from the trap of a ______and______and______ narrative. The key to an engaging story is a problem (but______), and solution (therefore______).

2) The voiceover

Although defined as a reading of the script, the voiceover should be anything but "scripted." Speak naturally, and in a conversational tone that includes inflection, pauses, and accents. The voiceover needs to convey the emotion of the story. Alan Alda, one of the founders of the Alan Alda Center for Communicating Science, observed that his casual talks with scientists "brought something out that you don't usually see when scientists are interviewed on television. That conversational tone made me realize that there was something that we could help scientists do to be more personal and be more available to a lay audience" (Stoller-Conrad 2016).

There are many options for recording and editing a voiceover (Table 4.1). StoryCenter recommends the software Sound Studio, iMovie, Audacity, and Final Cut Pro X (Lambert et al. 2010, 41). You must consider your budget, user experience, and computer operating system. The choice of tools for a digital storytelling project is not unlike the choice of equipment and materials for a scientific research project.

Table 4.1. Software for recording and editing audio

Software	Sound Studio	iMovie	Audacity	Final Cut Pro X	Adobe Audition
Approximate Price	$30	$15	free	$300	$20/month
User friendliness	Easy	Easy	Medium	Hard	Hard
Operating system	Mac	Mac	Mac Windows	Mac	Mac Windows

Find a small, quiet space without background noise for recording your voiceover. I recommend attaching an external microphone—such as a lapel or USB microphone—to your device in order to improve the quality of the recording. Perform a sound test and listen to the playback. Are you speaking too close to the microphone? Are you rushing through the script? Recording a clean, clear audio track is the key to easy editing. I use Adobe Audition to process all the audio files (.mp3 and .wav) for my digital stories. Both Adobe Audition and Final Cut Pro X are outfitted with an incredible suite of editing tools; however, the tradeoff is a high price tag and steep learning curve. If you record a quality audio track in the first place, a basic editing program will fulfill your needs. And remember: A digital story is not a professional movie production, nor should you expect the perfection of

Morgan Freeman or David Attenborough. Strive for a clear voiceover that relays your story and champions your personal voice.

3) The visual media

This is what really brings the story to life. Select media that is personal: faded photographs, clips from home videos, and hand-made drawings are more valuable than generic images from the Internet. By revealing personal details, you portray a vulnerability and honesty that invites the audience to connect and trust. Also consider how sequencing and juxtaposition can create additional layers of meaning; for example, a black and white photograph followed by a color photograph to suggest the passage of time. The adage "a picture is worth a thousand words" is relevant here. A script that has passed the 250-word limit can be shortened by replacing words with visuals. For instance, a detailed photograph of a pika in place of a description of its appearance. Ultimately, all visual media needs to be digitized and organized in a file folder on your computer. Be careful using images from outside sources—you must honor the fair and appropriate use of copyrighted material (this is not an issue with personal media). The website Pixabay is a good example of an online source for copyright-free images (http://www.pixabay.com).

4) The soundtrack

The soundtrack is not an essential part of the digital story; however, when used effectively, music and sounds can convey a deep, emotional tone. The soundtrack should complement, but not interfere with or overpower the voiceover. You can record music in the same way that you record a voiceover, or download music from an outside source. If opting for the latter, do so responsibly. The Free Music Archive website is a good place to start, because in addition to audio tracks it has a guide to music licensing and legal use (http://freemusicarchive.org/).

Preparation

Once the script is finished, the storyboard can start to take shape. "A storyboard is a place to plan out a visual story in two dimensions. The first dimension is *time*: what happens first, next, and last. The second is *interaction*: how the audio—the voice-over narrative of your story and the music—interacts with the images or video" (Lambert et al. 2010, 31). From my experience, media selection and storyboard creation are integrative; one doesn't necessarily come before the other. Furthermore, the final storyboard will be scattered with revisions and changes—part of the creative process. For an example of a storyboard template, modified from Lambert et al. (2010, 35), see Figure 4.1. Please note that this is only one of the many pages required to plan a complete story.

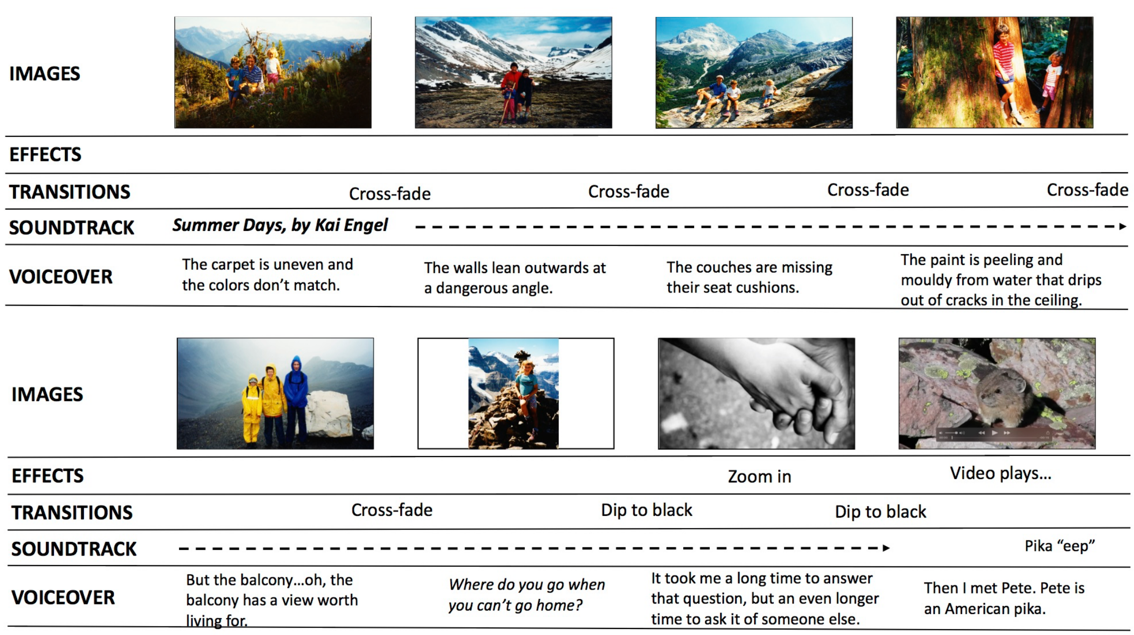

Figure 4.1. A segment of my digital story about being a pika researcher.

A storyboard increases the ease and efficiency of the next step in the digital storytelling process: combining the media into a cohesive video. This is certainly a technical challenge. However, in an age of online tutorials there is ample support for new users. StoryCenter recommends the software Final Cut Express for creating and editing video (Lambert et al. 2010, 60); although this program has been discontinued, Final Cut Pro X is roughly equivalent, and there are many more options to choose from (Table 1.2).

Table 4.2. Software for creating and editing video

Software	WeVideo	iMovie	Wondershare Filmora	Final Cut Pro X	Adobe Premiere Pro
Approximate Price	$5/month	$15	$45/year	$300	$20/month
User friendliness	Easy	Easy	Medium	Hard	Hard
Operating system	online	Mac	Mac Windows	Mac	Mac Windows

Once the software is established on your device, you need to progress through the following tasks: importing media; arranging media in a timeline; adding effects; exporting the video. I use Adobe Premiere Pro to create my digital stories. As with Adobe Audition, the learning curve is steep; however, tutorials abound on YouTube and answers come easily through Google searches. But if the art of video making seems unattainable, I recommend taking a workshop. For example, StoryCenter offers webinar courses on digital storytelling and three-day workshops throughout the United States (https://www.storycenter.org/publicworkshops/). For an idea of what a finished digital story looks like, browse through the samples on the StoryCenter website (http://www.storycenter.org/stories).

The Human Element

The Nobel Prize is a benchmark of excellence in the sciences. It has been awarded to such remarkable individuals as Albert Einstein, Marie Curie, James Watson, and Francis Crick (Nobel Media AB 2017). Their achievements advanced the fields of physics, chemistry, physiology, and medicine; their names fill the pages of school textbooks. But do their stories of innovation and discovery inspire students—the next generation of scientists?

A recent study published in the Journal of Educational Psychology holds an interesting answer (Lin-Siegler et al. 2016). The authors asked high school students to describe what kinds of people can be scientists: "Any person who has a spark of curiosity in himself or herself;" "Anyone who seems interested in the field of science;" and "People who can work hard" (Lin-Siegler et al. 2016, 314). Unfortunately, these egalitarian responses did not reflect the students' opinions about their own prospects as a scientist: "I don't get the best grades in science class right now. Even if I work hard, I will not do well" (Lin-Siegler et al. 2016, 314). Intrigued by this contradiction, the authors explored the belief that scientific achievement reflects ability instead of effort. They asked students to read struggle stories or achievement stories. Three examples from the study by Lin-Siegler et al. (2016, 320) are transcribed below:

Albert Einstein's Life Struggle Story:

> Growing up, Einstein saw his father struggle to provide for the family. Looking for work, Einstein's father moved the family several times for different jobs. This meant that Einstein had to change schools more than once during his childhood. Moving between schools was very difficult. Einstein not only felt out of place, but it was always challenging for him to catch up to what his new class was working on.

Marie Curie's Intellectual Struggle Story:

> It was frustrating that many experiments ended up in failure; however, Curie would not let herself stay sad for too long. Instead, she returned to where things did not work out and tried again. Often working hour after hour and day after day, Curie focused on solving challenging problems and learning from her mistakes. She knew that the way of progress was never easy, and later, she said, "I never yield to any difficulties."

Albert Einstein's Achievement Story:

> Albert Einstein won many awards in his life, including the 1921 Nobel Prize in Physics. His thoughts were so advanced that many contemporary scientists are still working on the ideas he talked about in 450 papers he published. In 1999, Time Magazine named Einstein the man of the century, and he is considered the father of modern physics because of his achievements.

After students read a collection of either struggle or achievement stories, Lin-Siegler et al. (2016) conducted surveys and assessed course grades. The results are surprising. Students exposed to scientists' struggle stories improved their grades, whereas students exposed to achievement stories did not (Lin-Siegler et al. 2016). Both the life struggle and intellectual struggle stories were superior learning motivators, particularly for low-performing students (Lin-Siegler et al. 2016). When interviewed, students explained that they connected with the failure and vulnerability of the scientists in the struggle stories (Lin-Siegler et al. 2016). They connected with what made the scientists "human."

The study by Lin-Siegler et al. (2016) emphasizes an important point: Science is a human endeavour. It is done by individuals, and within a societal context. Creativity, passion, and failure are as much a part of the advancement of knowledge as is evidence and systematic methods. Recognizing this relationship, the company who manages media rights for the Nobel Prize created a new programme: The Nobel Prize Inspiration Initiative (http://www.nobelprizeii.org/). Its purpose is to help Nobel Laureates share the story of their success. There are visits to universities, and interviews about everything from early life, to setbacks in research, to maintaining a work-life balance. Oliver Smithies is one of the featured interviewees. He shared the 2007 Nobel Prize in Physiology or Medicine for "discoveries of principles for introducing specific gene modifications in mice by the use of embryonic stem cells" (Nobel Media AB 2007). While undeniably impressive, this achievement is hard to relate to. However, Smithies attributes the beginning of his interest in science to something universal and simple: fixing an old, broken down car (Nobel Prize Inspiration Initiative 2012). As a young boy, Smithies would help his father with the constant repairs: "And so, you learn to do a little bit with your hands" (Nobel Prize Inspiration Initiative 2012, 0:42). He moved from cars, to transistor radios, to telescopes, and eventually…to stem cells.

The interviews with Nobel Laureates paint a more complete picture of what it means to be a scientist. For example, Martin Chalfie—the 2008 Nobel Laureate in Chemistry—explains that the main expression of his creativity is the "weekend experiment" (Nobel Prize Inspiration Initiative 2014b). The experiment that is "completely lunatic, that you're embarrassed to tell anyone about…if it works, you crow about it on Monday morning, and if it doesn't work you just simply ask people how their weekend went" (Nobel Prize Inspiration Initiative 2014b, 0:19). Randy Shekman—the 2013 Nobel Laureate in Physiology or Medicine—admits that his best ideas arise during seminars (Nobel Prize Inspiration Initiative 2015). When "the speaker is droning on in excessive detail, and it's so boring, but I'm, I'm in the middle of a row and I can't get up and leave, so I sit there and I daydream about my own work" (Nobel Prize Inspiration Initiative 2015, 0:23). Roger Kornberg—the 2006 Nobel Laureate in Chemistry—concedes that "there have been a lot of false eureka moments" (Nobel Prize Inspiration Initiative 2014a, 0:16). But also that disappointment is sometimes followed by discovery: “I knew I was right. And it was just exhilarating. That moment was absolutely one worth living for” (Nobel Prize Inspiration Initiative 2014a, 1:45).

The Nobel Prize Inspiration Initiative is an exemplar for better science communication. Through a series of interview questions, Nobel Laureates are demystified from “research gods” to normal people. Incredible, award-winning scientists are made relatable. In a similar way, digital stories help scientists connect. The personal elements—from the unique voiceover to the visual media—draw attention to the human side of science. The story elements—from the introduction of a problem to the setting of a mood—engage the audience. Through this dissertation I have shown that digital storytelling is a proven approach to science education, and a promising approach to science communication. As we advance into the future, and attempt to maintain that mutually supportive relationship between science and society, our methods of science communication need to keep pace. In the words of physicist, professor, and author Brian Greene (2008):

> Science is the greatest of all adventure stories, one that’s been unfolding for thousands of years as we have sought to understand ourselves and our surroundings. Science needs to be taught to the young and communicated to the mature in a manner that captures this drama. We must embark on a cultural shift that places science in its rightful place alongside music, art and literature as an indispensable part of what makes life worth living.

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Postface

The Doctor of Arts program is a unique experience for every graduate student. I chose a path with multiple intersections between the coursework, teaching internships, and research: An integrative approach that let me explore what is fundamental to how I think about and process the world. *Story*. But now that this work is complete, what next? A few months ago I came across a text that suggests a future direction. *Narrative, Identity, and Academic Community in Higher Education* (Attebery et al. 2017) documents a journey that began when faculty members, representing a number of different disciplines, were invited to talk about the role of narrative in their work. The resulting panel discussion occurred in front of a packed room; the "panelists found both common ground and challenging differences in their approaches" (Attebery 2017, 2). An anthropologist talked about inviting Peruvian Indians to tell stories of their illnesses so she could learn about traditional cultural patterns; a psychologist discussed the antagonism she uncovered between narrative evidence and statistical methods; a political scientist explained how competing narratives drive political debates; a communication scholar elucidated the role of storytelling in business culture. A photographer, linguist, and historian also shared their perspectives. Attebery (2017, 3) remarked that "the single panel discussion was only the beginning of a long process of working through implications for research, classroom practice, curriculum, and departmental structures." What later evolved was a collaboration between faculty in the College of Arts & Letters at Idaho State University; a series of interdisciplinary colloquia with participation from every department. Is it possible to produce a similar result in the College of Science and Engineering? What sorts of partnerships and discussions can story initiate amongst scientists? Answering these questions, and others, will be a challenge for the future.