COMPARING COMICS AND ILLUSTRATED TEXTS IN MULTIMEDIA LEARNING

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Abstract

The purpose of this research was to examine how different forms of media, in particular science comics and illustrated texts, contribute to different patterns of learning. While the standard illustrated text seen in a textbook has been a useful tool for instruction, science comics appear to be an alternative that could be used in lieu of media that use the traditional illustrated text format. The comic format, known more for its visual appeal to readers, is consistent with the principles of the Cognitive Theory of Multimedia Learning (Mayer, 2009), though comprehension may require different mechanisms (Cohn, 2013a). It was hypothesized that the joint processing of the narrative in the text and the visual narrative in the illustrations could make the comic format more effective for acquiring and remembering scientific information. Two experiments were conducted using explicit and inferential question types to compare performance between comics, illustrated texts, and text-only materials. Both verbatim and applied question types were included to see if performance changed based on the type of mental representation required to answer questions correctly. Image recognition checks revealed poor target-lure discrimination ability, which suggests that participants were not focusing on illustrated text images when presented. Null findings from these experiments may have implications for theory and future studies.

Keywords: multimedia learning, comics, visual narrative, situation model, memory

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I. Introduction

In academic settings, such as a college course, it is very common for students to learn from materials like textbooks. While there are differences that occur from one college textbook to the next, most share a commonality in that they include a lot of text and some diagrams. A content analysis of secondary science and senior biology textbooks found that each page averages hundreds of words in the main text but only 1.5 diagrammatic illustrations per page used to explain scientific concepts (Liu & Treagust, 2013). One sad fact about these traditional textbooks is that many college students do not complete the assigned readings from them (e.g., Gurung, 2017). There can be a variety of reasons for this -- perhaps students have time limitations, they may find the text to be boring, or maybe they have difficulty comprehending the information that is presented. Moreover, even though a textbook illustration may be designed to be cognitively useful, it may be functionally useless for readers unless they know how to use it as intended (Carney & Levin, 2002). Nevertheless, textbooks that predominantly focus on text (with a few diagrams) are not the only way to present information to students. A unique approach is to present the material in the form of a comic, which may offer a way to bridge this divide by scaffolding educational materials with stories.

The interest in using comics pedagogically is not a recent trend. In the mid-20th century, it appeared as though this alternative form of media was gaining enough legitimacy that researchers dedicated an entire journal to the study of comics in learning and education (Sones, 1944). Comics merely present stories by combining imagery with text. However, combining images and text is not unique to comics as most textbook diagrams include pictures along with labels or a caption. Comic, more specifically, is a medium characterized by the use of text embedded within an illustration that unfolds across multiple panels to convey a story. For the scope of this study, we will focus solely on the sub-genre of science comics, which are considered to be comics that are created to communicate science or educate readers about a particular scientific concept or theme (Tatalovic, 2009).

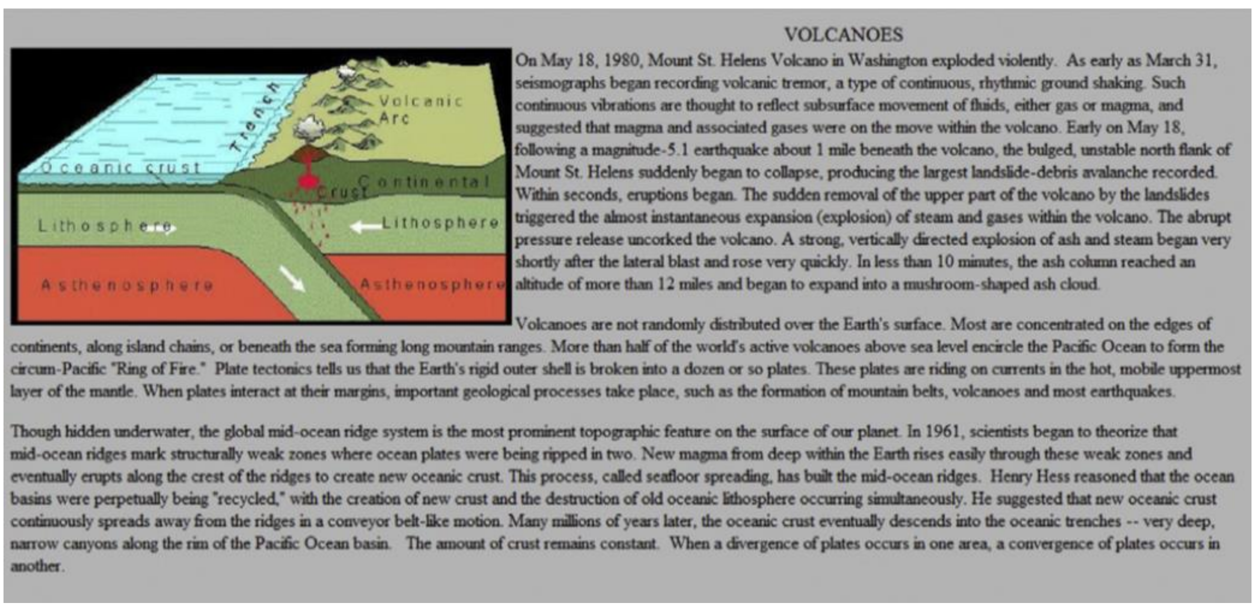
Few studies, and practically none in cognitive psychology, ask relevant questions regarding comics and the benefits they have on cognitive processes such as memory and comprehension. Those studies that compare comics to illustrated texts or text-only materials only go as far as to conclude that there may be differences. Furthermore, they can be limited in scope, have potential confounds, or fail to ask the follow-up questions regarding why. More specifically, why might students prefer comics over traditional textbooks? Clearly, some students acknowledge their preference towards an alternative form of multimedia, but do comics actually have more benefit than just being more visually appealing? It is one thing to demonstrate that students like comics, but if there are no benefits or there are similar learning outcomes to traditional textbooks (i.e., illustrated texts), what would compel educators to change course?

Overall, positive results from studies using comics suggest that it is worthwhile to understand further how comics may aid student performance. The issue currently is that extant literature is scarce concerning how science comics or other educational comics differ from illustrated texts. The goal of this thesis is to compare learning and memory performance between science comics and illustrated texts. The emphasis in this thesis is to determine the role of narrative structure as either an aid or interference in the learning process. If we want to understand how comics can be beneficial in a learning context, then we have to dive deeper into what kinds of texts and visualizations improve memory and comprehension of to-be-learned material. The following sections discuss the theories that aid our understanding of multimedia and visual languages. The use of comics in an educational context is subsequently described, followed by a proposal for two experiments.

II. Review of Related Literature

Cognitive Theory of Multimedia Learning

Multimedia instruction refers to the presentation of material using both words and pictures, intending to promote learning. As seen in Figure 1, readers can use the illustrations in multimedia as a reference to understand the text as they progress through it. The Cognitive Theory of Multimedia Learning (CTML; Mayer, 2009) rests on the premise that learners can better understand an explanation when presented with text and visuals than when presented with text alone. When compared to a non-illustrated text, the combination of text and images improves reading performance and retention (Carney & Levin, 2002; Gambrell & Jawitz, 1993).



VOLCANOES

On May 18, 1980, Mount St. Helens Volcano in Washington exploded violently. As early as March 31, seismographs began recording volcanic tremor, a type of continuous, rhythmic ground shaking. Such continuous vibrations are thought to reflect subsurface movement of fluids, either gas or magma, and suggested that magma and associated gases were on the move within the volcano. Early on May 18, following a magnitude-5.1 earthquake about 1 mile beneath the volcano, the bulged, unstable north flank of Mount St. Helens suddenly began to collapse, producing the largest landslide-debris avalanche recorded. Within seconds, eruptions began. The sudden removal of the upper part of the volcano by the landslides triggered the almost instantaneous expansion (explosion) of steam and gases within the volcano. The abrupt pressure release uncorked the volcano. A strong, vertically directed explosion of ash and steam began very shortly after the lateral blast and rose very quickly. In less than 10 minutes, the ash column reached an altitude of more than 12 miles and began to expand into a mushroom-shaped ash cloud.

Volcanoes are not randomly distributed over the Earth's surface. Most are concentrated on the edges of continents, along island chains, or beneath the sea forming long mountain ranges. More than half of the world's active volcanoes above sea level encircle the Pacific Ocean to form the circum-Pacific "Ring of Fire." Plate tectonics tells us that the Earth's rigid outer shell is broken into a dozen or so plates. These plates are riding on currents in the hot, mobile uppermost layer of the mantle. When plates interact at their margins, important geological processes take place, such as the formation of mountain belts, volcanoes and most earthquakes.

Though hidden underwater, the global mid-ocean ridge system is the most prominent topographic feature on the surface of our planet. In 1961, scientists began to theorize that mid-ocean ridges mark structurally weak zones where ocean plates were being ripped in two. New magma from deep within the Earth rises easily through these weak zones and eventually erupts along the crest of the ridges to create new oceanic crust. This process, called seafloor spreading, has built the mid-ocean ridges. Henry Hess reasoned that the ocean basins were perpetually being "recycled," with the creation of new crust and the destruction of old oceanic lithosphere occurring simultaneously. He suggested that new oceanic crust continuously spreads away from the ridges in a conveyor belt-like motion. Many millions of years later, the oceanic crust eventually descends into the oceanic trenches -- very deep, narrow canyons along the rim of the Pacific Ocean basin. The amount of crust remains constant. When a divergence of plates occurs in one area, a convergence of plates occurs in another.

Figure 1. Example of Multimedia Instruction on Volcanoes. In Jaeger & Wiley (2014)

Dual Coding

Mayer (2009) bases the theory of multimedia learning upon three core assumptions. First, dual coding assumes that humans possess separate channels for processing visual and auditory information (Baddeley, 1986; Clark & Paivio, 1991; Paivio, 1986), although these same assumptions also extend to separate pictorial and textual channels (e.g., Mayer, 2009). Dual coding can be beneficial because it can create multiple representations in memory, and because it can expand the amount of information that can be processed.

Limited Capacity

This leads to the second assumption of CTML, which is that there is a limited capacity as to how much humans can process at once. It is reasonable to question whether the simultaneous presentation of both pictures and text may overload visual working memory and force students to split their limited working memory capacity between representations (Moreno, 2006; Moreno & Mayer, 1999). The limited capacity assumption, taken from Baddeley's working memory model (Baddeley, 2001; Baddeley & Hitch, 1974) and Chandler and Sweller's Cognitive Load Theory (Chandler & Sweller, 1991; Sweller, 1988; 1994), suggests that humans are limited in the amount of information processed in each channel at one time. According to Baddeley's model, text and illustrations featured in multimedia are held within separate components of working memory. Textual information activates a verbal code that is rehearsed within the phonological loop until the information connects to a semantic representation stored in long term memory. At the same time, pictures and illustrations are retained in working memory as visual codes in the visuospatial sketchpad. This model is consistent with work by Paivio (1986), which describes the cognitive system as being equipped with subsystems for representing and processing language and nonverbal objects (i.e., images), respectively. Consequently, research on multimedia reliably demonstrates an enhancement of text by including illustrations (for a review, see Levie & Lentz, 1982).

Active Processing

Chandler and Sweller's Cognitive Load Theory (Chandler & Sweller, 1991; Sweller, 1988; 1994) builds on the working memory model by addressing the issue of system overload. If information is to be transferred into long-term memory, then the individual will have to both direct attentional resources to the to-be-learned information and hold it in the short-term store long enough to transfer it into long-term memory. The third assumption is that multimedia comprehension is an active process. One aspect of this is that people can make proactive decisions about where to focus attention. For example, the *picture superiority effect* is a consistent pattern in the literature that finds that pictures are recalled better than words (Gehring et al., 1976; Paivio & Csapo, 1973; Paivio et al., 1968). Despite these effects, there are contexts in which people may choose to favor text over pictures when reading material includes both (Beymer et al., 2007; Rayner et al., 2001). This departure may be because text and pictures serve fundamentally different roles during knowledge acquisition and are, therefore, subject to different kinds of processing (Schnotz et al., 2014). By using text-picture diagrams, Schnotz and Wagner (2018) demonstrate the distinct roles that text and pictures have during conjoint processing. They concluded that people use text to provide conceptual guidance but consider pictures to be external resources that can be used as needed.

Summary

According to multimedia theory, information travels through three stores of memory (Atkinson & Shiffrin, 1968). Pictures and images are first processed in the visual channel, and textual information passes through both visual and verbal channels. Because of limited processing capacity, attentional selection mechanisms then filter relevant images and sounds within working memory. After text and images are organized into their respective mental models, prior knowledge via long-term memory then integrates the two models into a unitized mental model (Kintsch & Kintsch, 1995).

During multimedia comprehension, readers first create a surface representation of the words and images. In conjunction with a surface representation, a propositional representation of the semantic contents is also generated. The surface and the propositional representation differ in that the former is a verbatim (i.e., analog) representation, whereas the latter takes on more of a gist (i.e., paraphrased) representation. The reader then constructs a mental model of the situational dimensions called a situation model (van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998). The situation model is considered the most long-lasting and stable type of representation and is influenced by the current state of affairs, as well as prior knowledge about the world (Morrow et al., 1997; Radvansky & Curiel, 1998; Radvansky et al., 1990).

Overall, the combination of both text and pictures seems to aid the comprehension process. It is likely that by supplementing text with visuals (as most textbooks do), readers are going to have a more dynamic mental representation because they can extract information from two sources that share overlapping depictions of the same information. However, simple text and illustration multimedia are not the only ways to present information, and formats outside of the mainstream, such as comics, are worth closer inspection as a tool for multimedia learning. The next section explores this format in more detail.

Visual Language Theory and Comics

When one considers how conventional forms of multimedia (e.g., traditional textbooks or eBooks) are constructed, it is typical to see some type of visualization (e.g., graphics, still photographs, video clips) that supports a large block of text on the page. In this multimedia interaction, the text and the visuals are designed in such a way that they can stand alone. Rarely are these two fully integrated. When pictures or illustrations are used, it is usually done in such a way that it augments or enhances the text. If multiple visuals are used, then readers have to scan through the text to comprehend the broader semantic relationship that connects one visualization to the next visualization. Comics are a unique form of multimedia in that comprehension involves a "visual language" of images to create complex interactions between the pacing of information in the text and the windowing of information via sequences of contiguous illustrations called panels.

Multimedia, in a general sense, is any medium that uses a combination of verbal (i.e., written or spoken) and visual (i.e., static or animated/dynamic) content to convey information. By these metrics, comics are also multimedia because they combine both text and illustrations, though not all multimedia are comics. For example, we cannot call a magazine article a comic, nor can we say that a news website is a comic just because it combines text and visuals. A comic is a specific type of medium and art form through which authors convey their ideas. Comics are best defined as "juxtaposed pictorial and other images in deliberate sequence, intended to convey information and/or to produce an aesthetic response in the viewer" (McCloud, 1993, p. 9). Like common multimedia, comics are used to convey information or elicit a response from the reader; however, the distinction is specific to the juxtaposition of images and the intention of these images to follow a specific order or sequence.

Typical comic strips traditionally found in newspapers (e.g., Garfield, Calvin & Hobbes, Peanuts) are simple designs where all the panels fall in the same row. With longer-form comics, this increase in length gives illustrators more latitude to create unique combinations of panels to fit onto a single page. Though comic page layouts can be constructed in various ways, readers are sensitive to combinations that deviate from a typical Z-path of left-to-right and down (Cohn & Campbell, 2015). Unlike an illustrated text, the illustrations are linked together through a shared narrative and an understanding of event sequences. If the panel in the top left of Figure 2 marks the beginning of an event, then each successive panel further elaborates details about the story represented in the text.

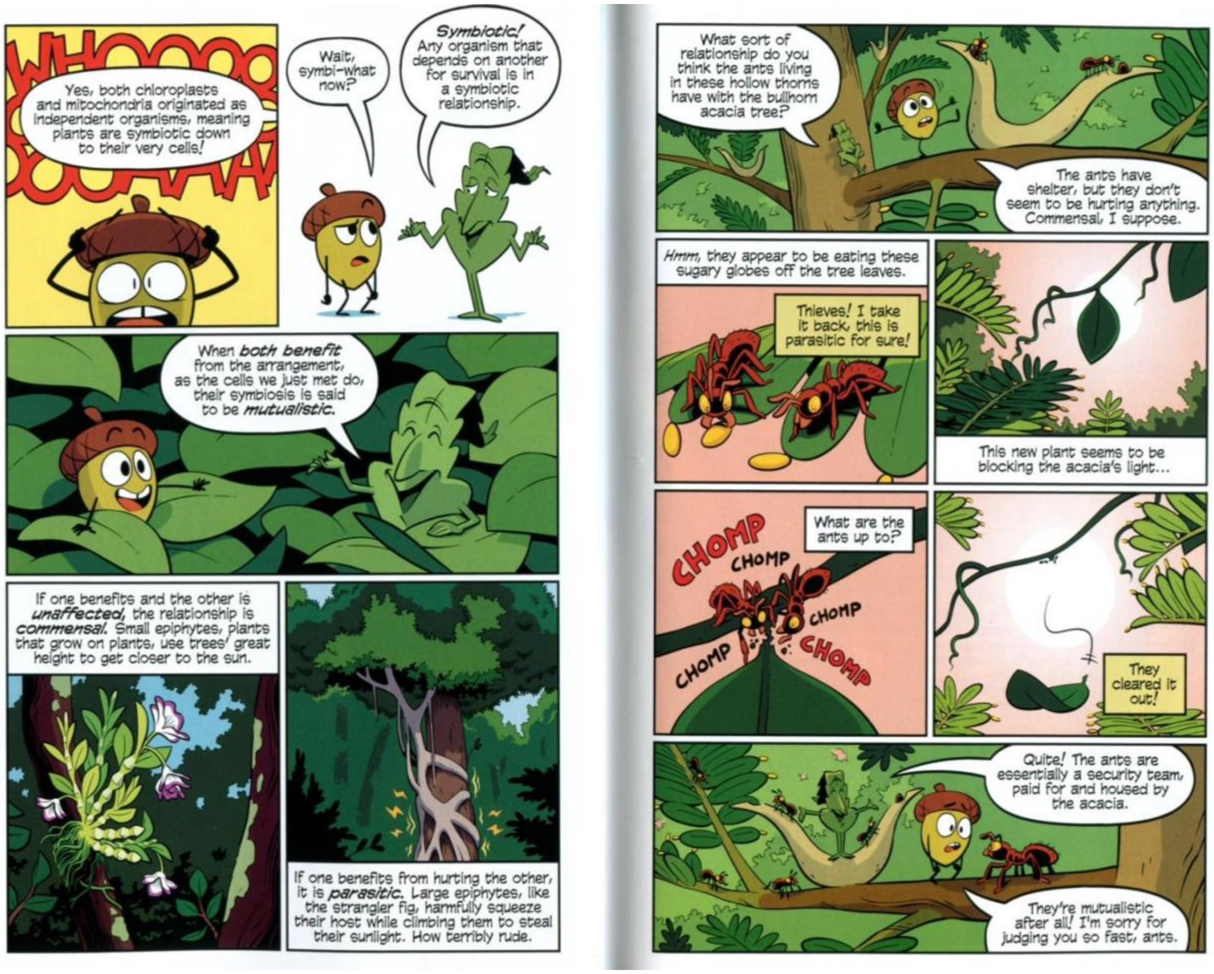


Figure 2. Example of a common comic page layout. In *Science Comics: Trees: Kings of the Forest* (Hirsch, 2018)

In his seminal book *Understanding Comics* (1993), McCloud wrote, “It’s your job to create and recreate me moment by moment, not just the cartoonist’s” (p. 59). What he means is that reading comics is not a passive process. There has to be a mechanism on readers’ end that allows them to understand that the events in the first panel preceded the events in the second panel. McCloud’s theories were some of the first to take a systematic approach to how readers understand comics by taking the position that there are cognitive mechanisms that allow us to perceive and make sense from sequential images. Because comics fracture the conventions of space and time, there must be a mechanism that facilitates understanding or else we would perceive comic panels as isolated events. One cannot simply state that a transition has taken place without acknowledging that the brain has a significant role in supporting this process. McCloud’s theory, however, can only account for the one-to-one relationships between adjacent panels. It makes no mention of the mechanisms that facilitate the processing of semantic relationships between nonadjacent panels.

Visual Language Theory (Cohn, 2013) argues that visual languages, such as comics, are structured and processed in much of the same way as written or spoken languages. Visual and written languages likely share similar cortical regions and cognitive systems that support online comprehension, including how it is structured (Cohn et al., 2014; Cohn et al., 2012) and how it is segmented (Magliano et al., 2012). Furthermore, visual and textual narratives are considered to share visuospatial and linguistic working memory systems (Magliano et al., 2016). Just like textual discourse, understanding visual sequences require the interaction between bottom-up and top-down processes.

Visual Language Theory proposes that a collection of comprehension mechanisms described as a Visual Narrative Grammar (VNG; Cohn et al., 2012) guides visual discourse. According to Cohn, VNG uses similar functional principles as verbal or written syntax to organize words into meaningful sentences (Cohn et al., 2014). Research consistently shows that the processes involved in comprehending visual narratives mirror those involved in processing sentences (Cohn et al., 2014; Cohn et al., 2012; Magliano et al., 2016). VNG is consistent with psychological theories of textual discourse (Magliano & Zacks, 2011; Zwaan & Radvansky, 1998) such that updating must occur as relationships change between units in a sequence. Unlike McCloud's theories on panel transitions, VNG accounts for these relationships by proposing that semantic information contained in individual panels maps on to a categorical role within a constituent structure.

Syntax in verbal languages is a set of rules or guidelines that distinguish random strings of words from coherent sentences. Visual languages use a similar cognitive system to discriminate between random images and panels in a sequence. Cohn et al. (2012) conducted a study in which participants were asked to identify a target panel in one of four types of wordless comic sequences. Normal sequences had both a narrative structure and semantic relationship between panels. Structural or semantic only sequences had either narrative structure or semantic relationship between panels, respectively. Scrambled sequences had neither narrative structure nor semantics. Researchers found that reaction times were fastest in normal sequences, intermediate in structural and semantic only sequences, and slowest in scrambled sequences, suggesting that there are processing benefits to related pictures in a predictable sequence. Furthermore, results from this study suggest that semantics and structure operate independently but need to come together to facilitate comprehension and build a mental structure of the "event."

The Parallel Interfacing Narrative and Semantic (PINS; Cohn, 2019) model argues that the processing of visual narrative sequences occurs across two parallel and interfacing levels of representation. As a visual narrative sequence unfolds, representations for processing the narrative structure and the semantic relationships go through simultaneous forward- and backward-moving processes of accessing, predicting, and updating these representations. Through narrative processing, readers must access their inferred understanding of narrative categories (Cohn, 2014a). Inferential processing of narrative constituents allows the reader to make predictions about which panel to read next to facilitate comprehension and assist when ambiguities arise (Cohn, 2013b; Cohn, 2014b). As panel sequences unfold, readers continuously update their representation of the narrative structure as presented by the ordering of panels. The semantic processing of information cascades through similar processes of accessing semantic networks, using prior knowledge to make predictions about events, and storing it in a situation model which updates its internal structure as it encounters new information. Like most theories of comprehension, the PINS model acknowledges that top-down and bottom-up mechanisms influence model construction. When readers create situation models from visual narratives, they receive inputs from both the environment as well as semantic knowledge stored in memory.

To summarize, these theories make the argument that comics are distinct from other forms of multimedia. Specifically, comics consist of side-by-side illustrations that follow a particular order. Unlike multimedia, comic panels take up the entire page, rather than text like one would find in a multimedia textbook. To make sense of these panel sequences, the reader must have an inferred understanding of the rules that govern how panels can be combined and grouped to convey meaning. By following this Visual Narrative Grammar, readers are offered advantages in their processing and comprehension of comics. While readers access semantic knowledge, a simultaneous process of processing narrative structure is also ongoing. These two levels of interacting representations not only afford readers the ability to retrieve what they know about the depicted event but also to update their mental model as new information becomes integrated. The mental operations involved in making sense from comics appear to be advantageous when used in conjunction with educational materials.

Comics as Pedagogical Tools

Following the initial surge in interest, research that emphasized the scientific bases of understanding comics and visual narratives disappeared almost completely from the scientific literature, especially ones that approached the subject from a cognitive perspective. Instead, discussions about comics remained in the confines of language arts for decades. As a result, a simple internet search would probably yield many articles, blog posts, and anecdotes from educators about using comics in the classroom without any peer-reviewed research to back their claims (e.g., Cohen, 2020). Some fail to see comics as a legitimate medium for learning and claim that comics are ephemeral and should not be given any earnest critical or theoretical attention (Bongco, 2000). Thus, as a result, there was a long-held assumption that comics could not compete with the traditional textbook in the space of multimedia learning.

However, in the last decade alone, comic research has reemerged with a significant increase in the number of disciplines that feature comics as tools to communicate information. For example, comics have been used in science (e.g., Hosler, 2008; Tatalovic, 2009; Tribull, 2017), technology (e.g., Lin & Lin, 2016; Lin et al., 2015; Rota & Izquierdo, 2003), engineering (Landherr, 2016), and medicine (e.g., Green & Myers, 2010; Mayo, 2011; Williams, 2012). These examples suggest that comics have a great appeal in many different fields.

Benefits of Comics

Instructors attribute the success of comics in education to the ability of the format to break down complex textual structures into an easy-to-comprehend format, as nascent or struggling readers can use comics to transition to more challenging materials (McPherson, 2006). If this format is used to target struggling students, comics can promote literacy, especially for those who either do not enjoy reading or have a fear of failure (Gorman, 2003; Koenke, 1981). One suggestion is that comic books are useful teaching tools because they are motivating and engaging if used to educate rather than entertain students (Versaci, 2001; Yang, 2008). When students are given comics as learning materials, they often come away showing greater interest and feeling more confident that they know and understand the concepts (Landherr, 2016; Lin et al., 2015). Surprisingly, Lin et al. (2015) discovered that participants who learned from a text booklet instead of a comic on the same topic saw a decrease in their interest and enjoyment of learning contrary to what researchers expected. In fact, there was a significant correlation between score differences from pre- and post-tests and changes in attitude.

There are studies to suggest that even interest and motivation can manifest into a student's overall achievement (Damopolli & Rahman, 2019). These results, however, require closer examination as the interaction with levels of achievement may qualify them. For example, Lin and Lin (2016) found that high achievers benefit more from a text booklet. In contrast, medium achievers improved their scores with a comic, suggesting that there may be a select range of individuals that stand to benefit from the comic format.

Studies that focus on general knowledge acquisition and understanding of concepts also found that comics are just as good at communicating information as their text-heavy counterparts. One example is from Hosler and Boomer's (2011) study in which the instructor assigned students readings from a comic textbook for a single semester. Compared to their traditional science textbook, students that received the comic textbook increased their understanding of scientific concepts. Although these results appear encouraging, it is worth mentioning that students were assigned readings from their comic textbooks and readings from their traditional Biology textbook, meaning that improved understanding was not a direct effect of learning with the comic textbook. Instead, learning with comics interacted with the content already covered by the traditional textbook. Some argue that even if comics help students retain information, textbooks are still considered essential to set up background knowledge (Syma et al., 2013). When asked, most students agreed that learning initially with a textbook made it easier to draw connections between ideas and know where to look for information, suggesting that there might be nothing unique about comics that distinguishes itself from textbooks or illustrated texts.

Using a similar approach as Hosler and Boomer (2011), Spiegel et al. (2013) gave high school students either a story in comic format or a nonfiction essay about viruses. Although comics showed comparable gains in terms of knowledge acquisition, students that were given the comic were nearly five times more likely to want to continue reading educational materials than the group that received the nonfiction essay. What is remarkable about these two studies is that the most considerable improvement came from the students who did not previously consider themselves as "science people," thereby elucidating the widespread appeal of comics.

Over the years, comics have demonstrated a strong track record of associated cognitive benefits. When it comes to meta-cognition, most students believe that using comics makes it easier to learn concepts and helps students improve their learning and retention (Özdemir, 2017; Short et al., 2013). In addition to benefits to motivation and achievement, comics also improve memory and understanding. When compared to text, those that read comics were shown to have better accuracy and verbatim recognition (Alexio & Sumner, 2017; Short et al., 2013; Wang et al., 2019). Most importantly, these effects extend into long-term memory, with some finding that students' recall of terms learned from a comic were well-preserved two years after completing the course (Nagata, 1999). These studies, however, are limited by the fact that researchers did not account for participants' prior knowledge. One possibility could be that those individuals with better recognition and recall had some previous exposure to the topic that allowed them to quickly and efficiently map information onto an existing mental structure. This idea is consistent with Scheiter et al.'s (2014) suggestion that individuals who had prior knowledge to apply to the interpretation of animations were more likely to preserve learning outcomes. If previous experience influences how well individuals learn from comics, then future research will stand to benefit from taking this into account. Altogether, these studies suggest that various factors may interact with the comic format, which could explain away potential benefits.

Comics and Multimedia Principles

Although the interest in using and exploring possible benefits of comics is growing, much of the existing research focuses on the application of comics rather than breaking down what it is about educational information in a comic format that promotes better learning. If we consider comics to be an earnest medium for learning, then we would expect them to adhere to the principles of multimedia learning. Indeed, comics take advantage of several principles of multimedia learning, suggesting further examination as a pedagogical tool.

First is the *multimedia effect*, which refers to the finding that deeper learning occurs from a multimedia explanation (i.e., presented in words and pictures) than from words alone. In studies that compared comics to text only materials (e.g., Alexio & Sumner, 2017), comics saw notably better performance. This improvement is most likely because comics, through its integration of words and pictures, allow for dual coding (Mayer & Massa, 2003). However, these findings do not say anything specific about the benefits of comics in particular, as the enhancement of text with illustrations have been commonplace in the literature for decades (Levie & Lentz, 1982).

The *spatial contiguity effect* assumes that students learn more deeply from multimedia explanations when corresponding words and pictures are presented near to rather than far from each other on the page or screen. When items are close in proximity, there is less of a load placed on working memory to hold both words and pictures in mind before integrating them into a single representation (Chandler & Sweller, 1991). Spatial contiguity may be one area where comics have an inherent advantage over traditional textbooks. One of the ways in which comics combine text and illustrations is through "emergent" relationships (Cohn, 2013c). Emergent relationships are when the author uses a placeholder, most often a story character, to hold the text. In comics, this is usually placed within a device called a speech balloon. An inherent relationship is where the text is part of the illustration but serves no function in conveying information (e.g., text in a book). The tails on speech balloons function as a way to connect the text to a particular character. If the tail on a speech balloon is too far removed from the carrier, then the graphic integration is less likely to occur, and the comic may be no more effective than an illustrated text (Cohn, 2013c).

Another multimedia principle that ties into the previous one is the *personalization effect*, which states that students learn more deeply when the words are presented in conversational style rather than formal style (Moreno & Mayer, 2000). This effect comes from the notion that learners may be more willing to accept that they are in a human-to-human conversation, including all the conventions of actively trying to understand what the other person is saying. Although one cannot find conversations in all genres of comics, science comics often use central characters that act as the narrator and teacher. This protagonist communicates information as if it were the authors speaking directly to their readers (see Figure 3). In conjunction with close spatial proximity, students could benefit from comics more than illustrated text as a result using more personalized language (e.g., “You might want to try this”) versus a more formal tone (e.g., “Problems such as these are solved in the following process”).

Finally, the *coherence effect* is another multimedia principle that is relevant to comics. This idea refers to the finding that student learning can be negatively affected when multimedia include extraneous material. Here, the notion is that the extraneous material interferes with the comprehension process by encouraging learners to pay attention to irrelevant words or images that may prime irrelevant schemas. Therefore, a well-constructed illustration must follow certain design principles that highlight the function and relationships between parts in a system. To this extent, “decorative” is the best way to describe comics containing irrelevant information. For example, the sequence below in Figure 3 describes Newton’s First Law of Motion.

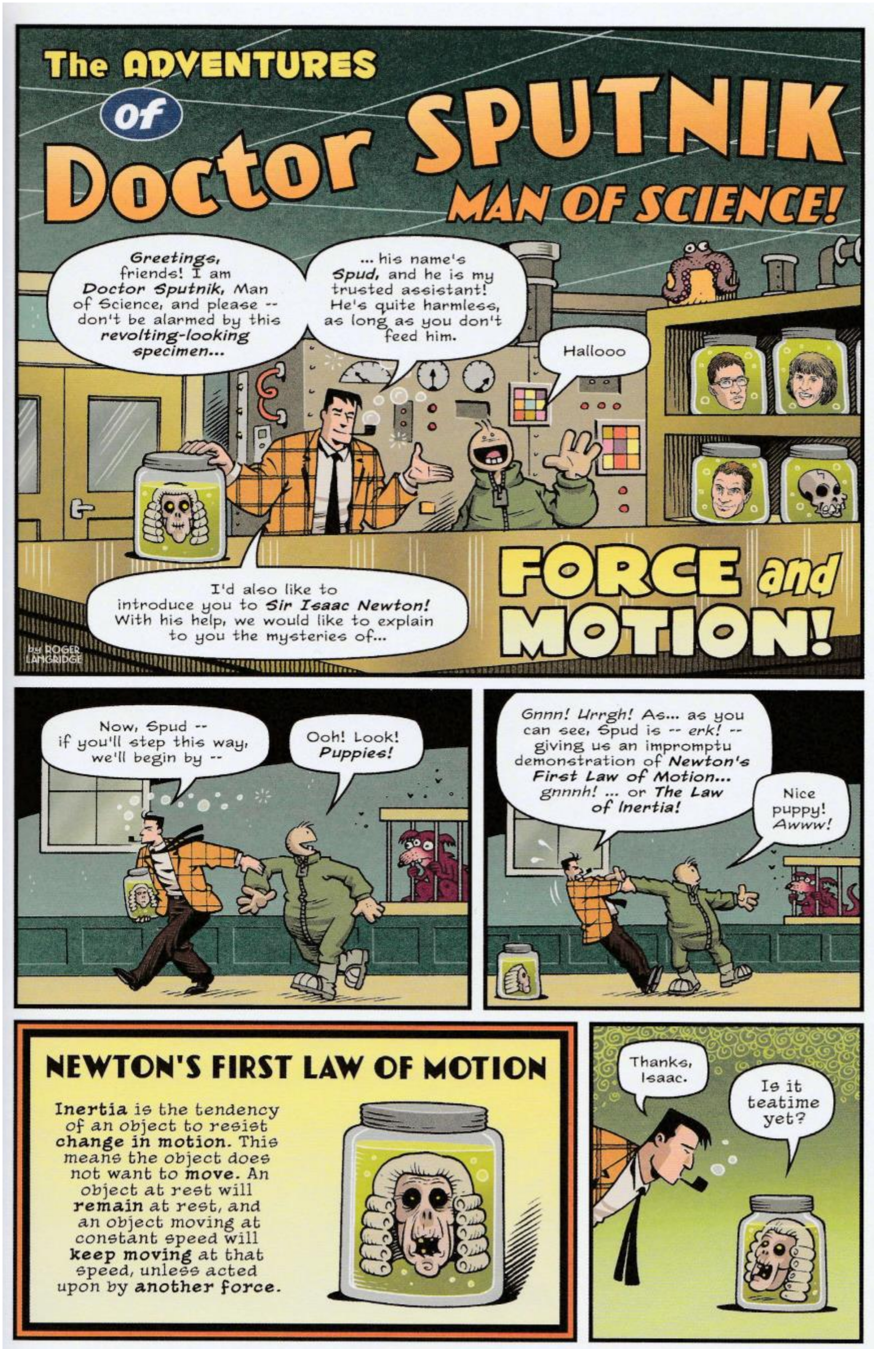


Figure 3. Example of a comic page that includes "decorative" panel illustrations. In *The Adventures of Doctor Sputnik: Man of Science* in *Reading with Pictures* (Elder, 2014)

One could argue that the final panel on this page contains no information about physics. Because the illustration introduces characters previously included, it fits into a greater event sequence. While decorative illustrations like these may increase readers' interest, they have little effect on increasing performance in learning environments (Magner et al., 2014). More importantly, decorative illustrations may compromise metacomprehension abilities, meaning that it causes learners to feel overconfident in how well they understand a concept (Jaeger & Wiley, 2014). Because comics connect the illustrations through the same narrative arc, panels that could be considered "decorative" in isolation are unitized as part of the same event representation.

To process a comic, readers must continuously update their mental models. This process of updating appears to be ongoing and continuous throughout each panel of a visual narrative (Cohn & Kutas, 2015; Osaka et al., 2014). It is unclear how much this continuous updating affects cognitive abilities compared to an illustrated text. In an illustrated text, the illustrations are used as supplemental materials to aid in text comprehension, whereas readers only use the text for conceptual guidance (Schnotz & Wagner, 2018). Comics could better explain more dynamic processes by allowing the event to unfold across several panels. Because model updating is assumed to occur as each panel is encountered, this may require more complex cognitive skills than reading text alone (Schwarz, 2002). However, illustrations that depict an event are processed faster than illustrations that depict a state (see Figure 4; Molinari & Tapiero, 2007). These results align with findings from Cohn et al. (2012), where participants had faster reaction times in a normal sequence (i.e., narrative structure and semantic relationship) than a sequence with only a semantic relationship between the panels. If readers benefit from illustrations in a sequence, then we would expect readers to benefit from comics to a greater extent than an illustrated text because the illustrations align with the same narrative arc. Conversely, the visuals in an illustrated text, share only a semantic relationship to the text. Therefore, readers could benefit from incremental and continual updating of their event representation that occurs when they read comics.

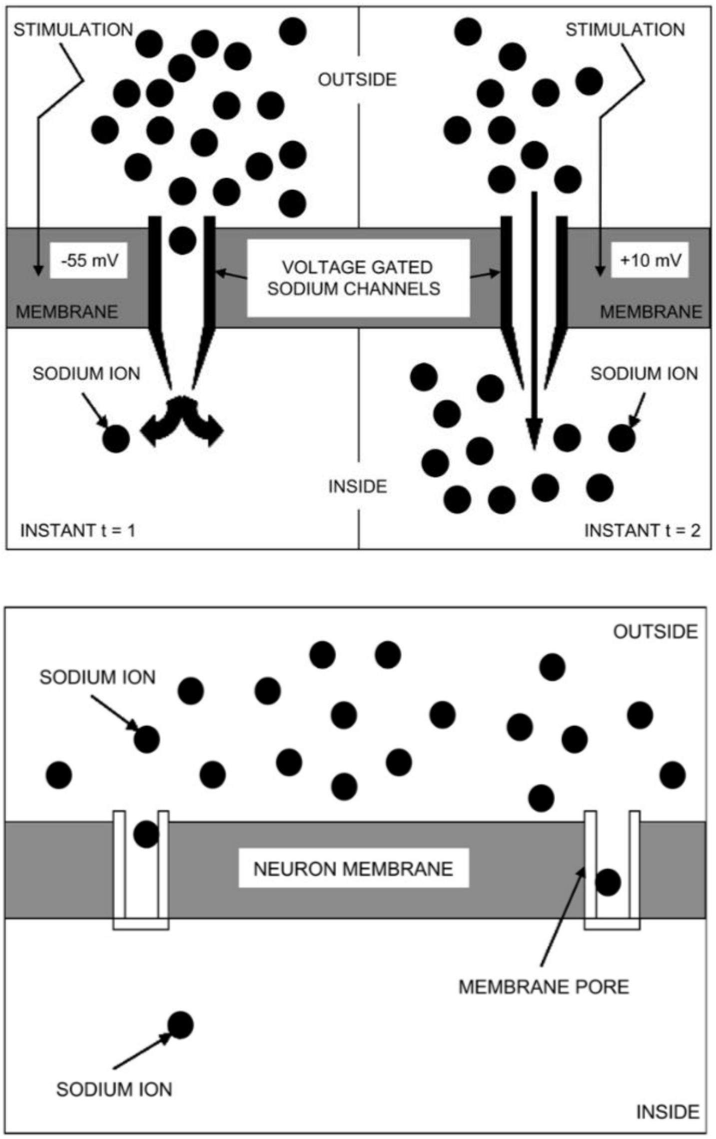


Figure 4. Event (top) and state (bottom) illustrations on the movement of sodium ions in and out of a neuron. In Molinari & Tapiero (2007)

Summary

Overall, this body of research suggests that comics have the potential to promote engagement and enhance cognitive abilities, especially compared to text-heavy multimedia. What is unclear is whether this interacts with the extent of prior knowledge. If researchers want to understand how to maximize these benefits, then these materials must undergo more rigorous testing to accomplish these goals. This study is the first to examine science comics through a CTML framework. Previous literature has established that differences occur between comics and textbooks (e.g., Hosler & Boomer, 2011) and also comics and illustrated texts (e.g., Wang et al., 2019). However, few studies have attempted to figure out why such differences may appear. We take the position that when students are given science comics in place of illustrated texts, memory performance will improve because the illustrations follow a narrative sequence in parallel with its associated text.

III. Current Research

Purpose of Study

The current study examines learning and memory differences between science comics, illustrated texts, and text-only formats. To accomplish this, a within-subjects design was used where participants read two topics from science comics, two from illustrated texts, and two from text-only materials. The primary focus was to compare science comics to illustrated texts since we are interested in understanding what structural qualities comics possess that can explain benefits to learning and memory. While comparing science comics and illustrated texts are the main interest, text-only materials were used as controls, as multimedia learning assumes that deeper learning occurs when materials are presented using both text and illustrations. It is known that illustrations enhance text processing and the online construction of a situation model (Gyselinck, 1996; Gyselinck & Tardieu, 1999), and that students learn better from text and pictures than from text alone (Carney & Levin, 2002; Gambrell & Jawitz, 1993). However, because comics meet several criteria for better multimedia learning tools, this would suggest that the comic format is a better way to present multimedia information than illustrated texts.

A point of concern with previous studies that compared comics to illustrated texts is the limited experimental control researchers had over their experiments. Although many of these studies have demonstrated statistically significant effects, how researchers collected their data cannot rule out the possibility of alternative explanations. For example, Hosler and Boomer (2011) found that after assigning students a comic textbook on biology, their understanding of the subject improved at the end of the semester. Despite these significant results, the comic and traditional textbooks were both administered as assigned readings (i.e., homework) throughout the term, meaning that the experimenters had no control over the amount of time that students actually spent on either the comic textbook or the traditional textbook. Also, students were reading both the comic textbook and the traditional textbook in the same lesson plan, which means that we do not know how much reading the traditional textbook influenced the learning from the comic textbook and vice versa. In studies that compared comics to text booklets, researchers mailed out their study materials to participants (Lin & Lin, 2016; Lin et al., 2015), which again limits the degree to which we can attribute any benefits directly to the comic.

To the best of our knowledge of extant literature, the experiments in this thesis have the most overlap with the methods used in Alexio and Sumner's (2017) study. To reiterate, researchers assigned participants either a science comic about biopsychology, the same comic but replaced with incongruous images, or just the text. They found that memory for the material was highest in the regular science comics, followed by the text-only condition, and lowest for the comic with random images. While we might conclude from these findings that memory for information presented in a comic format is better than an illustrated text format (i.e., incongruous comic), there were several shortcomings of their design that limit how much we can take away. First, it is highly likely that a comic with incongruous images is going to see the least amount of benefit because the images are causing interference with the to-be-learned information contained in the text. These results come with little surprise as Cohn et al. (2012) found that comic sequences that shared neither semantics nor a narrative structure took participants the longest to identify the target panel. Concerning the *coherence effect* of multimedia learning, the incongruous comic from Alexio and Sumner (2017) included extraneous items that caused a mismatch between what participants were asked to study and what they were visualizing (see Figure 5). This incongruous comic condition, however, has little resemblance with a traditional textbook and so it is of greater utility to compare comics to illustrated texts that elect to use images or illustrations which highlight relevant information in the text (Carney & Levin, 2002). That is, we wanted to know if there is something unique about the comic format that improves memory and learning and not just the multimedia aspect of combining text with an illustration.

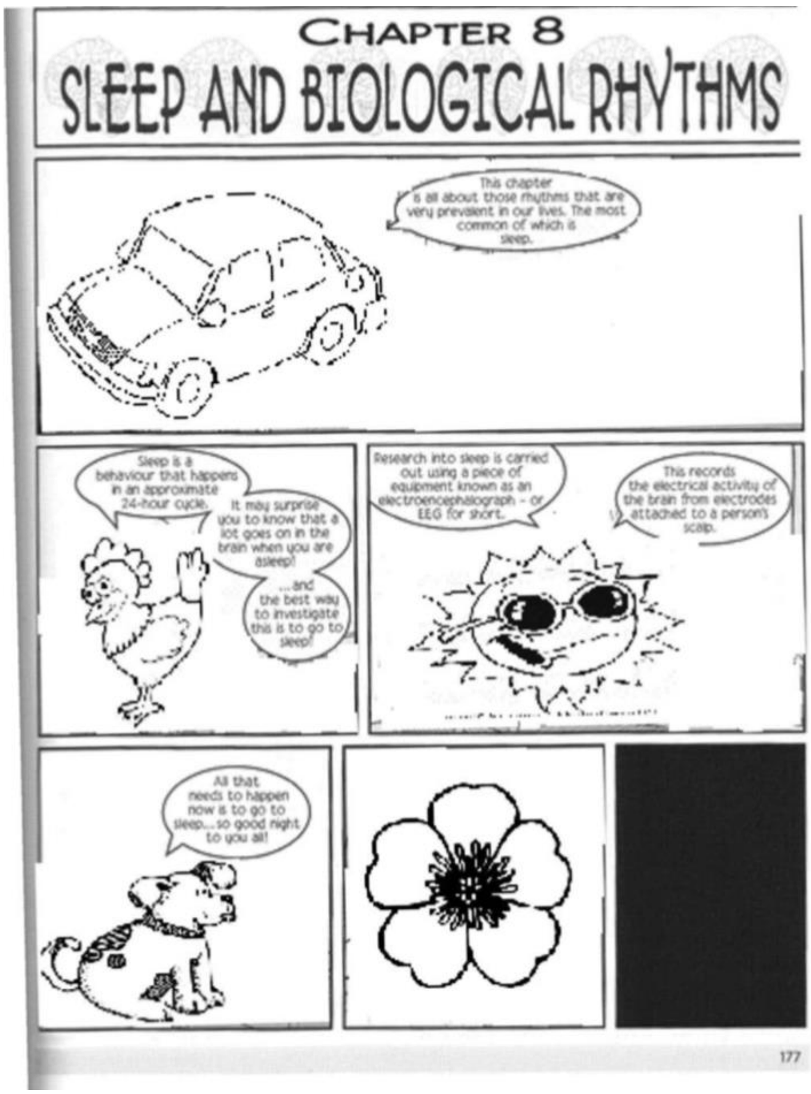


Figure 5. Example of an "incongruous comic". In Alexio & Sumner (2017)

In addition to the questionable materials used in the Alexio and Sumner (2017) study, other limitations that we improved upon include accounting for participants' prior knowledge by including the same questions before and after learning and generalizing the effect of the comic format across different topics. A key feature of learning from text is linking the textual information with prior knowledge (Kintsch, 1994), thereby activating semantic networks of context-relevant information. By linking information with prior knowledge, readers can understand what they are reading and can simulate future situations. However, we know that prior knowledge does vary within and between participants. Not accounting for prior knowledge is a significant limitation of previous studies (e.g., Alexio & Sumner, 2017). By studying only one specific area (e.g., biopsychology) and not accounting for prior knowledge, participants that performed better with comics could have possessed higher prior knowledge. Because prior knowledge was not measured, this limits the extent to which we can firmly conclude that the comic format was driving the observed effect. To correct for these limitations, this thesis used short excerpts from six books each covering a separate science concept (e.g., bats, trees, solar system). The materials were taken directly from First Second Books' *Science Comics* series to avoid the rigorous process of selecting topics and developing stories around those subjects. Choosing a variety of topics from this series allowed for greater generalizability and avoided pitfalls around testing participants with prior knowledge in each area. We assume that using several diverse topics decreases the likelihood that a single participant will have high prior knowledge on every topic.

In this study, we assessed prior knowledge and comic fluency before participants read any of the materials. To assess prior knowledge, participants answered the same questions given during the pre-learning phase as they did the testing phase. By administering the same set of questions before and after the learning phase, the difference score between pre- and post-learning indicates the change in memory as a function of format. To assess comic reading experience, participants completed the Visual Language Fluency Index (VLFI; Cohn, 2014c). The VLFI is a quantitative measurement to assess fluency by gauging participants' comic reading and drawing habits, as well as subjective assessments of self-described "expertise." The first use of the VLFI was in Cohn et al. (2012), where researchers demonstrated that ERP amplitude differences were greater for participants with high fluency scores, suggesting that participants were activating their "visual narrative grammar." Accounting for participants' prior exposure and fluency with comics is important because comic literacy may account for more of the variability in performance, and participants could potentially display a bias towards the novelty of comics (Farinella, 2018). Likewise, students with previous exposure to comics are also considered to have better comprehension than those without prior exposure (Nakazawa, 2016). Taking these into account may provide more explanatory power to how individual differences contribute to observed differences in learning with science comics or illustrated texts.

Following the completion of all six topics, participants answered a series of knowledge-based questions to assess their long-term memory. The procedures in Experiment 1 tested participants' change in knowledge by using a set of questions that focused only on explicit aspects of the text. In Experiment 2, participants were tested on both explicit and inferential aspects of the text. These two types of questions can be said to relate to different degrees of understanding, and our methods include these to test if readers are processing comics and illustrated texts at different levels of representation. If we want to test how different multimedia formats influence memory and knowledge acquisition, then it is also critical to understand how readers use that knowledge when they must apply it via inferencing.

Explicit, or verbatim, questions are ones in which all the information can be found directly in the text and relies only on surface features to answer correctly. In contrast, implicit, or inferential, questions require the reader to use contextual cues to draw connections not specifically mentioned in the text. This type of question requires the reader to interact with deeper forms of understanding, most likely at the level of the situation model. For example, if the text states, "A machine that can fly or swim without a human to control it is called a drone." An explicit question might look like this: "What do you call a machine that can fly or swim without a human to control it?" Notice how the explicit question includes verbatim text. In this situation, the way the question is framed results in a high degree of overlap with the original memory trace. Readers essentially match the text with their memory representation. An inferential question might ask: "Bill sees a plane flying around, but it appears as though there is no pilot inside maneuvering it around. Bill could be looking at a...". In this inferential question, readers cannot rely on matching the question with a verbatim memory representation. Instead, they have to take the idea units "plane" and "no pilot," recall the knowledge that has been acquired about the nature of drones (i.e., without human control), and then apply it to Bill's situation.

Finally, in addition to measures of prior knowledge and learning, participants also answered questions regarding their interest in the learning materials. Previous literature consistently demonstrates that students or participants that received comics rated these materials much more favorably compared to textbooks, illustrated texts, text booklets, or text alone (e.g., Hosler & Boomer, 2011; Landherr, 2016; Lin et al., 2015). Compared to a textbook, 82% of participants had higher favorability for the comic, whereas 80% would recommend using the comic for future learning (Short et al., 2013). In another study, 94% of participants answered positively and encouraged the use of comics in future courses (Landherr, 2016). Conversely, textbooks decrease interest in the subject (Lin et al., 2015). When asked to rate them on a variety of dimensions, students rate textbooks rather critically, particularly regarding the attractiveness, comprehensibility, number of non-verbal components, organization, and the connection of the content with everyday experiences (Knecht & Najvarová, 2010).

Hypotheses

General

The multimedia principle (Mayer, 2009) assumes that when text and illustrations are combined, deeper learning occurs. As previous literature suggests, illustrations enhance text processing (Gyselinck, 1996; Gyselinck & Tardieu, 1999; Levie & Lentz, 1982) and support student learning (Carney & Levin, 2002; Gambrell & Jawitz, 1993). Thus, we expected that after reading either a science comic or an illustrated text, participants' performance would improve significantly more than their improvement after reading text alone. As a general trend, we expected that science comics would be rated significantly higher than illustrated text and text-only formats as participants often rate comics very favorably in studies which also include illustrated texts (e.g., Short et al., 2013).

Experiment 1

When compared to illustrated texts, we expected that participants that read the science comic format would perform better on explicit questions, as Short et al. (2013) found that verbatim recognition was higher for those that received a comic compared to a textbook. This prediction is consistent with previous literature, which suggests that comics, generally, are remembered more often than illustrated texts (e.g., Wang et al., 2019).

Experiment 2

Given the nature of inferential questions, these types of questions require the use of a deeper form of comprehension, presumably at the level of the situation model. During comprehension of comics, both visuospatial and linguistic memory systems support readers' ability to generate inferences (Magliano, Kopp et al., 2012; Magliano, Larson et al., 2016). Additionally, earlier studies show that at each panel, comic readers update both visual and textual content (Cohn & Kutas, 2015; Osaka et al., 2014). With an illustrated text, readers process text and visuals independently. Because of this discontinuity, the unified model of text and illustration is most likely updating asynchronously. That is, the text is processed first, and then pictures are used to support further model construction (Glenberg & Langston, 1992; Schnotz & Wagner, 2018). When presenting a picture before the text, processing both components is more efficient (Eitel et al., 2013). If readers process text in an illustrated text for conceptual guidance and then use the pictures to support the text, this would imply that the primary focus of an illustrated text is, in fact, the text. Because comics are more of a visually dominant format, we might expect that comics are going to be processed more efficiently because readers process illustrations first, followed by reading the text. Likewise, if readers update their models at each panel, this could suggest that a situation model constructed from a science comic is superior to one constructed from an illustrated text by way of more consistent top-down and bottom-up model refreshing. Therefore, we predicted that after reading from science comics, memory scores on explicit and inferential questions would be significantly greater compared to illustrated texts.

IV. Methods

Experiment 1

Participants

Using effect size estimates from previous literature (e.g., Alexio & Sumner, 2017, Levie & Lentz, 1982), an a priori power analysis was conducted to determine an approximate sample size that will allow us to detect an effect if there is indeed one in the population. To achieve a power of 0.80 and a moderate effect size of 0.50 ($\text{partial } \eta^2 = 0.20$), a total of 51 undergraduate student participants were recruited from the University of Nevada, Las Vegas subject pool. In return for their participation, participants were awarded research credits as a part of their requirements for course completion. One restriction was that participants were required to be fluent in English as they were learning from texts that were written only in English. Additional exclusionary criteria included: (1) intoxication, (2) performance at chance (or near 0), and (3) memory disorder (e.g., epilepsy or brain damage) One-hundred one participants were removed from the dataset for failing to meet minimum performance requirements. Mean comic reading fluency on the VLFI was considered low, at 9.08 (SD = 6.99).

Materials and Procedure

Science Comics

In Experiment 1, participants were presented with 6 different materials, each focusing on a different topic. The topics were chosen from a corpus of existing comics that have been published by First Second Books' Science Comics series. Titles (abbv.) include *Dinosaurs* (Reed, 2016), *Plagues* (Koch, 2017), *Polar Bears* (Viola, 2018), *Robots and Drones* (Scott, 2018), *Solar System* (Mosco, 2018), and *Trees* (Hirsch, 2018).

Visual Language Fluency Index (VLFI)

Participants began the experiment with the Visual Language Fluency Index (VLFI; Cohn, 2014c) to determine their familiarity with and usage of comics (see Appendix B). The VLFI is a quantitative measurement that assesses the fluency related to comic reading expertise. This measurement asks participants to rate the frequency of their comic reading habits for several different types of comics (comic books, comic strips, graphic novels, Japanese manga) and their frequency of drawing comics on 7-point scales, ranging from 1 ("Never") to 7 ("Always"). Participants also rated their comic reading expertise and drawing ability on 5-point scales, ranging from 1 ("Below average") to 5 ("Above average"). Because most individuals do not have expertise in drawing comics, this scale is weighted more heavily towards comic comprehension. The maximum possible score is a 52.5, with participants falling into categories of low (< 8), average (10-19), and high (>20) fluency.

Pre-learning Test Phase

Following the VLFI, participants were given a set of explicit questions that were used for both the pre-learning and post-learning phases. For each one of the 6 topics, participants answered the same 6 explicit questions that they received during the post-learning test. Following each question, participants rated their confidence on a 6-point scale, ranging from 1 ("I am not confident at all.") to 6 ("I am very confident."). Confidence ratings were included as a separate exploratory measure in addition to participants' memory test score. Pre-learning test scores are each worth 6 possible points for each topic and 36 points total. Example items for the pre- and post-learning explicit tests are listed in Appendix A.

Media Versions

As described earlier, this study used pre-existing science comics from publisher *First Second Books*' *Science Comics* series. In the science comic version (see Appendix C), materials were kept in their original comic form. From there, two additional versions were constructed. The illustrated text version shared the same text as its science comic counterpart (with some modifications), however illustrations from the original comic were replaced with textually relevant images (see Appendix D for an example). Text modifications include presenting character names or describing actions in brackets to clarify vague or ambiguous wording that could otherwise be deciphered from the material in its original form. If a text passage in the science comic unfolded over several panel illustrations, the illustrated text used one text-relevant illustration for the entire passage. The text-only version (see Appendix E) used only the text from the illustrated text version as a control condition. Because illustrated text and text-only versions have been adapted from the science comics, these versions will be presented in black text on a white background. Science comics and illustrated texts will be presented in full color with no alterations.

Learning Phase

All participants read short excerpts from each of the 6 science comic topics. For each one of the topics, participants read one of three versions. The select version that participants received was assigned in a counterbalanced manner across all 6 topics so that participants viewed each version twice. The learning phase began with participants reading each text individually until all 6 texts were read. Participants then proceeded through the learning materials at their own pace. To account for participants that either sped through materials or failed to maintain focus, attentional checks were implemented throughout the experiment. Participants that failed these minimum requirements had their data removed.

Post-learning Test Phase

After reading through all 6 materials, participants began the testing phase. The testing phase consisted of the same 36 multiple choice questions administered for the pre-learning tests. Questions were then presented individually to limit any influence between items on the same topic. Following each question, participants again rated their confidence on a 6-point scale, ranging from 1 (“I am not confident at all.”) to 6 (“I am very confident.”). Similar to the learning phase, topics in the post-learning test phase were tested independently and in the same order that they were presented in the learning phase. By presenting topics in the same order for learning and testing, this allowed for roughly equivalent delays between study and test for each topic. The testing phase ended after the participant finished all 36 questions.

Image Recognition Check

An image recognition check was included after the post-learning questions to identify whether participants viewed the illustrations in the illustrated texts. In this task, participants were presented a sequence of 20 images including equal numbers of previously seen illustrations and similar lures. They were asked whether the illustration was previously seen in the learning phase and then asked to rate their confidence on a 6-point scale ranging from 1 (“I am not confident at all.”) to 6 (“I am very confident.”). Participants were allowed to complete this task at their own pace.

Participant Interest Questionnaire

Following the image recognition check, participants completed 2 interest questions for each of the 3 formats. This questionnaire (see Appendix F) is a quantitative measure to assess participant interest in the format as well as the likelihood that they would recommend it to another person. The questions are: “If you were to use [*Insert format*] to learn new information, how likely are you to this format?” and “If a friend wanted to learn new information, how likely are you to recommend [*Insert format*]?” Participants rated their responses on a 5-point scale from 1 (“Very unlikely”) to 5 (“Very likely”).

Experiment 2

Participants

Again, using effect size estimates from previous literature (e.g., Alexio & Sumner, 2017, Levie & Lentz, 1982), an a priori power analysis was conducted to determine an approximate sample size that will allow us to detect an effect if there is indeed an effect in the population. To achieve a power of 0.80 and a moderate effect size of 0.50 (partial $\eta^2 = 0.20$), a new sample of total of 51 undergraduate student participants that did not participate in Experiment 1 were recruited from the University of Nevada, Las Vegas subject pool. In return for their participation, participants were awarded research credits as a part of their requirements for course completion. Again, one restriction was that participants must be fluent in English as they were learning from texts that were written only in English. Additional exclusionary criteria included: (1) intoxication, (2) performance at chance (or near 0), and (3) memory disorder (e.g., epilepsy or brain damage). Sixty-five participants were removed from the dataset for failing to meet minimum performance requirements. Mean comic reading fluency on the VLFI was considered average at 10.38 (SD = 6.86).

Materials and Procedure

Materials and procedures in Experiment 2 were identical to Experiment 1. In addition to the 6 explicit questions on the pre- and post-learning tests, participants also answered 6 inferential questions (see Appendix G for example). The distinction between these question types is that explicit questions are written to include verbatim text whereas inferential questions are written to include learned concepts but require readers to make connections between ideas not overtly stated. The post-learning test phase will include 12 multiple choice questions on each topic. Again, questions will be presented individually to limit any influence between items on the same topic. A recognition check was included to measure participant engagement with the illustrated text images. The experiment ended after the participants finished their interest questionnaire.

V. Results

Experiment 1

Pre-learning vs. Post-learning

A paired samples t-test was used to compare participants learning scores before and after the learning phase (i.e., pre-learning vs. post-learning). A significant difference was found between pre-learning (M = 2.71, SD = .70) and post-learning (M = 4.86, SD = .79) scores, $t(50) = 17.78$, $p < .001$, Cohen's d = 2.88, indicating that participants showed improvement in their performance after the learning phase.

Media Effect for Explicit Questions

A one-way repeated Measures ANOVA was conducted to compare mean difference scores ($M_{\text{post-learning}} - M_{\text{pre-learning}}$) between illustrated text (M = 2.108, SD = 1.11), science comic (M = 2.28, SD = 1.15), and text-only (M = 2.13, SD = 1.14) materials. Difference scores were computed by subtracting the number of correct answers in the pre-learning test phase from the number of correct answers in the post-learning phase. Analyses revealed no significant differences between means, $F(2, 100) = .534$, $p > .05$, $\eta p^2 = .01$. No follow-up analyses were performed.

Media Effect for Explicit Question Confidence Ratings

A one-way repeated measures ANOVA was conducted to compare confidence ratings for explicit questions before and after the learning phase (pre-post difference) between science comic (M = 2.38, SD = 1.02), illustrated text (M = 2.25, SD = 1.10), and text-only (M = 2.32, SD = 1.05) materials. Analyses revealed no significant differences between mean confidence ratings, $F(2, 100) = .56$, $p = .571$, $\eta p^2 = .011$ (observed power = .141). No follow-up analyses were performed.

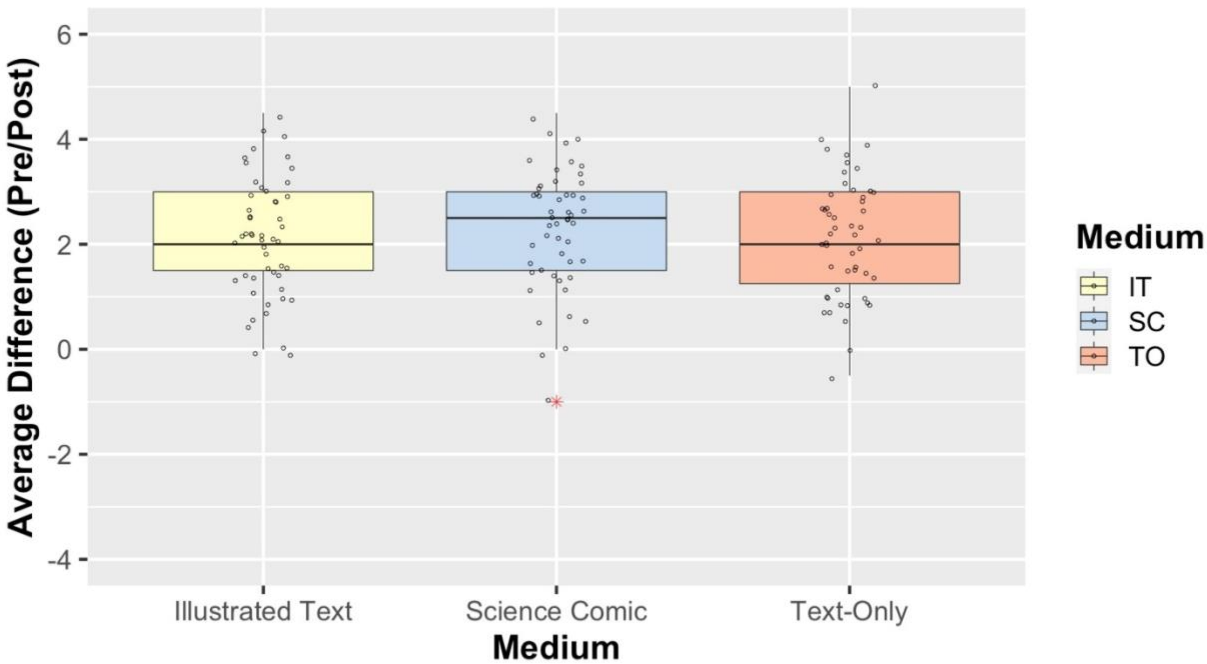


Figure 6. Boxplot of explicit question difference scores in Experiment 1. *Note.* Difference scores were computed by taking the number of questions correctly answered in the pre-learning phase and subtracting that from the number of questions correctly answered in the post-learning phase. A red asterisk indicates an outlier difference score.

Multimedia Effect

A paired samples t-test was used to compare mean difference scores between multimedia (i.e., with illustrations) (M = 2.17, SD = .90) and text-only (M = 2.13, SD = 1.14) materials. No significant difference between mean difference scores was found between materials with and without illustrations, $t(50) = .283$, $p > .05$, Cohen's d = 0.039.

Participant Media Interest (Personal)

A one-way repeated measures ANOVA was conducted to compare mean ratings for how likely a participant would continue to use a science comic (M = 3.63, SD = 1.02), illustrated text

(M = 3.41, SD = 1.06), or text-only (M = 2.94, SD = 1.19) materials. There was a significant difference between media format for mean personal interest ratings, $F(2, 100) = 4.79$, $p = .010$, $\eta p^2 = .087$ (observed power = .784). Participants reported that they were more likely to use the science comic (mean difference = .687, p = .008) and illustrated text formats (mean difference = .469, p = .042) over the text only format. There was no significant difference between science comic and illustrated text formats (mean difference = .219, p = .289), suggesting that participants were equally likely to use a multimedia format.

Participant Media Interest (Recommendation)

A one-way repeated measures ANOVA was conducted to compare mean ratings for how likely a participant would recommend science comic (M = 3.53, SD = 1.16), illustrated text (M = 3.37, SD = 1.11), or text-only (M = 2.68, SD = 1.09) materials for a friend. Again, there was a significant difference between media format for mean recommendation ratings, $F(2, 100) = 7.63$, $p < .001$, $\eta p^2 = .132$ (observed power = .941). Participants reported that they were more likely to recommend the science comic (mean difference = .849, p = .002) and illustrated text formats (mean difference = .687, p = .001) over the text only format. Similar to personal interest ratings, there was no significant difference between science comic and illustrated text formats (mean difference = .162, p = .463), again suggesting that participants were more likely to use a multimedia format over text-only format.

Experiment 2

Pre-learning vs. Post-learning

Paired samples t-tests were used to compare pre-learning versus post-learning scores for explicit and inferential question types. For explicit questions, a significant difference was found between pre-learning (M = 2.27, SD = .71) and post-learning (M = 3.83, SD = .97) scores, $t(50)$ = 12.97, p <.001, Cohen's d = 1.84). For inferential questions, a significant difference was also found between pre-learning (M = 2.12, SD = .60) and post-learning (M = 2.43, SD = 1.01) scores, $t(50)$ = 2.13, p =.038, Cohen's d = .373). These significant differences show that participants' performance improved after the learning phase.

Media Effect for Explicit Questions

A one-way repeated measures ANOVA was conducted to compare mean explicit question difference scores between illustrated text (M = 1.60, SD = 1.32), science comic (M = 1.58, SD = 1.32), and text-only (M = 1.52, SD = .97) materials. Similar to Experiment 1, analyses revealed no significant differences between explicit difference score means, $F(2, 100) = .08$, p = .925, ηp^2 = .002. No follow-up analyses were performed.

Media Effect for Explicit Question Confidence Ratings

A one-way repeated measures ANOVA was conducted to compare confidence ratings for explicit questions before and after the learning phase (pre-post difference) between science comic (M = 1.77, SD = 1.18), illustrated text (M = 1.71, SD = 1.21), and text-only (M = 1.80, SD = 1.19) materials. Similar to Experiment 1, analyses revealed no significant differences between mean confidence ratings, $F(2, 100) = .34$, p = .710, ηp^2 = .007 (observed power = .104). No follow-up analyses were performed.

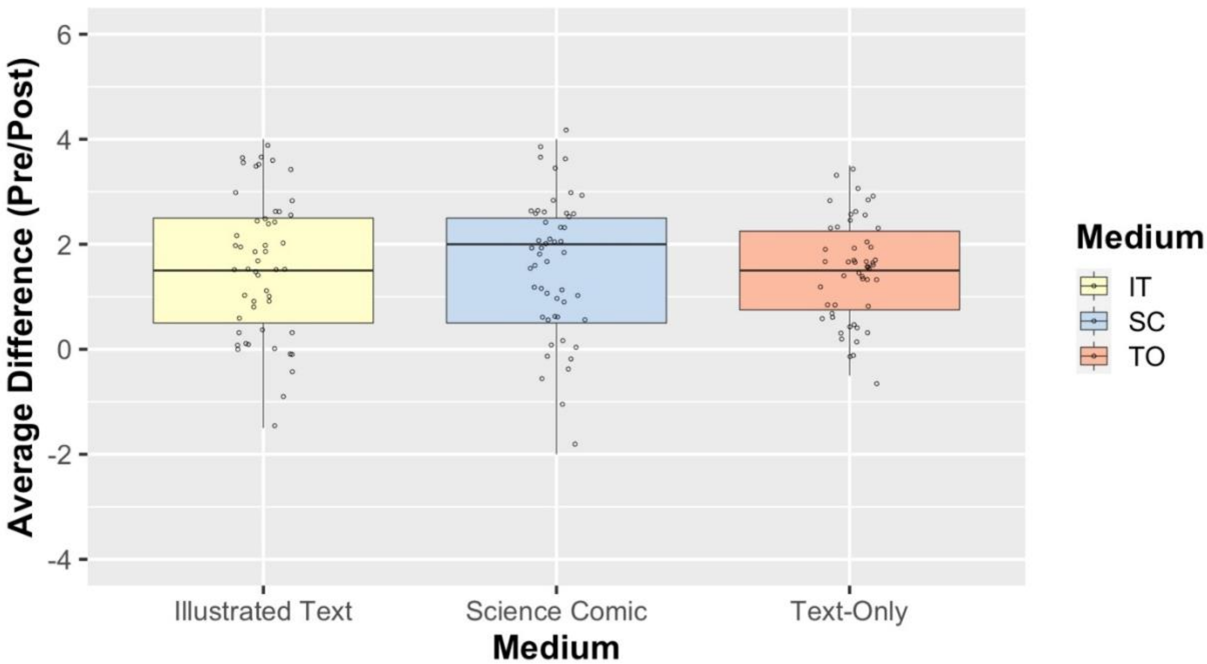


Figure 7. Boxplot of explicit question difference scores in Experiment 2.

Media Effect for Inferential Questions

A one-way repeated measures ANOVA was conducted to compare mean inferential question difference scores ($M_{\text{post-learning}} - M_{\text{pre-learning}}$) between illustrated text (*M* = -.20, *SD* = 1.87), science comic (*M* = .53, *SD* = 1.33), and text-only (*M* = .52, *SD* = 1.26) materials. The three group means showed significant differences, $F(2, 100) = 5.78$, $p = .004$, $\eta p^2 = .104$. Participants presented learning materials with the comic medium had significantly higher difference scores on inferential questions than learning materials presented using the illustrated text medium (mean difference = .725, p =.003). Learning materials formatted with only text also received significantly higher difference scores on inferential questions than illustrated texts (mean difference = .716, p = .042). Science comics, however, showed no significant difference from text-only materials (mean difference = .010, p = 1.000).

Media Effect for Inferential Question Confidence Ratings

A one-way repeated measures ANOVA was conducted to compare confidence ratings for inferential questions before and after the learning phase (pre-post difference) between science comic (*M* = 1.53, *SD* = 1.05), illustrated text (*M* = 1.53, *SD* = 1.06), and text-only (*M* = 1.42, *SD* = 1.19) materials. Similar to explicit questions, analyses revealed no significant differences between mean confidence ratings, $F(2, 100) = .59$, $p = .559$, $\eta p^2 = .012$ (observed power = .145). No follow-up analyses were performed.

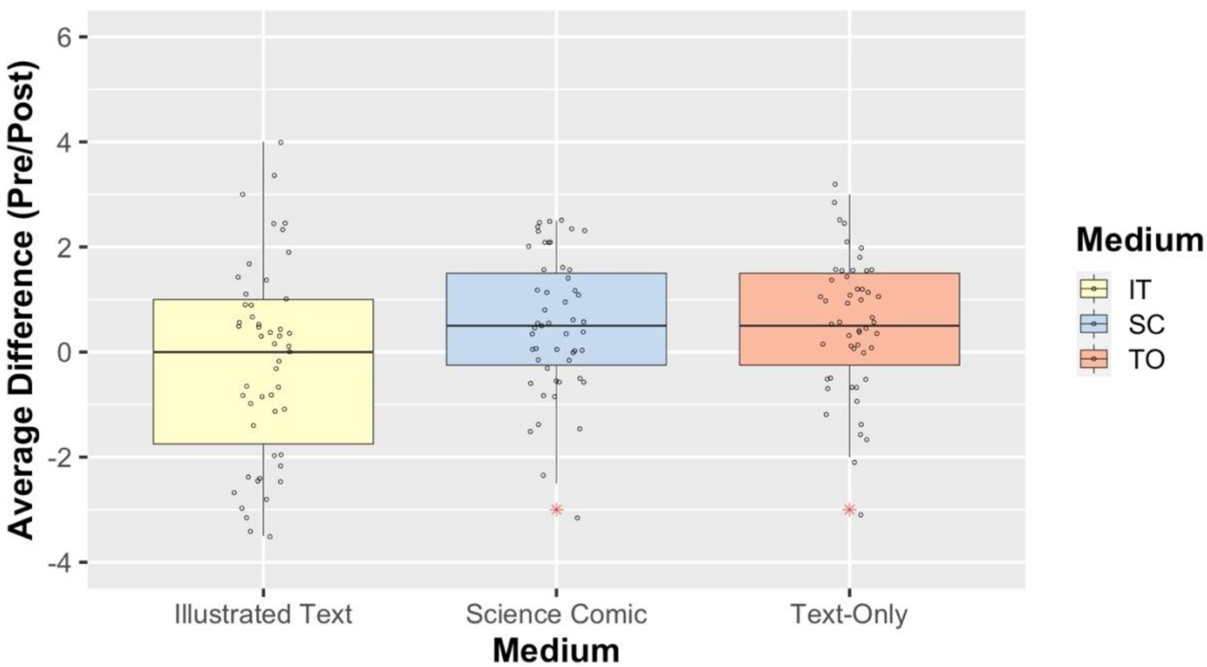


Figure 8. Boxplot of inferential question difference scores in Experiment 2.

Multimedia Effect

A paired samples t-test was used to compare mean difference scores for explicit and inferential questions between multimedia and text-only materials. For explicit questions, no significant difference was found between multimedia (M = 1.59, SD = .98) and text-only materials (M = 1.52, SD = .97; $t(50)$ = .53, p =.601, Cohen's d = .074). Likewise, no significant difference was found between multimedia (M = .17, SD = 1.45) and text-only materials (M = .52, SD = 1.26) for inferential questions ($t(50)$ = -1.47, p =.149, Cohen's d = -.205).

Participant Media Interest (Personal)

A one-way repeated measures ANOVA was conducted to compare mean ratings for how likely a participant would be to continue to use a science comic (M = 3.47, SD = 1.17), illustrated text (M = 3.43, SD = .96), or text-only (M = 2.76, SD = 1.24) materials. Like Experiment 1, there was a significant difference between media format for mean personal interest ratings, $F(2, 100)$ = 7.87, p < .001, ηp^2 = .136 (observed power = .948). Participants reported that they were more likely to use the science comic over the text-only format (mean difference = .706, p = .006). Similarly, participants reported they were also more likely to use the illustrated text formats over the text-only format (mean difference = .667, p = .002). There was no significant difference between science comic and illustrated text formats (mean difference = .039, p = .780), suggesting that participants would rather use a multimedia format over a text-only format.

Participant Media Interest (Recommendation)

A one-way repeated measures ANOVA was conducted to compare mean ratings for how likely a participant would be to recommend science comic (M = 3.45, SD = 1.06), illustrated text (M = 3.51, SD = .88), or text-only (M = 2.45, SD = 1.17) materials for a friend. Like Experiment 1, there was a significant difference between media format for mean recommendation ratings, F(2,

100) = 17.61, p < .001, ηp^2 = .260 (observed power = 1.00). Participants reported that they were more likely to recommend the science comic (mean difference = 1.00, p < .001) and illustrated text formats (mean difference = 1.06, p < .001) over the text only format. Again, there was no significant difference between science comic and illustrated text formats (mean difference = -.059, p = .736), once more showing that participants were more likely to use a multimedia format over text-only format.

VI. Discussion

The purpose of this study was to investigate how science comics differ from illustrated texts and text-only materials using explicit and inferential question types, which should theoretically use different forms of mental representations. In Experiment 1, participants showed no significant differences between all forms of media when given explicit questions. In Experiment 2, participants again showed no significant differences for explicit questions but performed significantly worse when using illustrated texts relative to science comics and text-only materials. However, conclusions drawn from this study are tentative, as follow-up analyses revealed significant lack of engagement with illustrations from the illustrated text. An image recognition check following the post-learning section revealed that participants clearly did not encode the illustrations, which calls into question the extent to which participants used the illustrations at all. For instance, the average *d*' for illustration recognition was 0.49 and -0.21 in Experiments 1 and 2, respectively. Performance at this level suggests that subjects may not have looked at the illustrated text images when scrolling through the story text (see Methods), thereby limiting conclusions drawn about differences with that condition and the others. Nonetheless, our null findings may have implications for theory and future studies.

The Cognitive Theory of Multimedia Learning (Mayer, 2009) is an important theoretical framework that assumes that explanations using both text and visuals lead to better understanding than when using only text. However, despite previous literature finding a significant benefit from using multimedia (e.g., Sones, 1944; Gambrell and Jawitz, 1993; Carney and Levin, 2002), our results did not show any difference between materials with and without illustrations. If text-redundant illustrations improve learning, then we would expect to see performance improve after using both science comics and illustrated texts. The results from our second experiment, however, seem to suggest that positive learning outcomes may depend more on the way in which text and illustrations are integrated seeing that participants were less inclined to use the illustrated text images.

The Integrated Model of Text and Picture Comprehension (ITPC; Schnotz, 2014; Schnotz & Bannert, 2003) posits that a working theory of comprehension should be able to predict under what circumstances the addition of a picture to text is beneficial for comprehension or knowledge acquisition and under what conditions it is detrimental. Schnotz and Bannert (2003) demonstrate that the utility of the illustration depends upon the condition with which it is being applied. What this suggests is that the dual coding assumption of CTML may be too broad to simply assume that all illustrations will aid memory and knowledge acquisition. The addition of illustrations may depend more on context, and even when they are included, they provide no utility if students do not know how to use them (Kinzer et al., 2011).

Overall, these results come as a surprise as a review by Levie and Lentz (1982) revealed that, of the 46 experimental comparisons obtained, the presence of text-redundant illustrations improved learning information in the text in all but one comparison (85% of which were statistically significant). Though we cannot make definitive statements about why a multimedia effect was absent, age and education may play role. Again, referring to the 46 experimental comparisons mentioned above, only three studies used college-aged participants, one of which resulted in non-significance. This may be because elementary-aged students stand to benefit the most from multimedia design considering the amount of effort required for comprehension as one is learning to read (Anglin, Vaez, Cunningham, 2004; Gambrell & Jawitz, 1993; Mayer, 2009).

The novelty of this experimental design was the use of question types that rely on different levels of representation. Explicit questions require the use of surface level representations, as participants need to match their memory to specific word phrases to answer questions correctly (i.e., fill-in-the-blank). Inferential questions rely on deeper levels of representation (i.e., propositional and situation model) because participants must extrapolate ideas and concepts from the story to select the correct answer. Contrary to what was hypothesized, participants showed no differences for explicit questions in either experiment, suggesting that learners are not going to find any added benefit from one medium over the other when the question requires the use of a surface level representation. These findings are somewhat inconsistent with previous studies that found that individuals who read comics or graphic novels had better accuracy and verbatim recognition (Alexio & Sumner, 2017; Short et al., 2013; Wang et al., 2019) than those who read illustrated texts or text-only materials. However, Alexio and Sumner (2017) and Short et al. (2013) used between-subjects designs in their studies, which could tentatively explain why we were unable to detect any significant differences with our within-subjects design.

Limitations/Future Directions

There are a few limitations to this study that we will address. As noted above, the level of performance on the manipulation check at the end of the illustrated text condition suggests that subjects did not use the illustrations. The nature of the online formatting required participants to scroll the page to view the illustrations. Although text prompts were included to "examine [illustrations] if they are presented," participants may have simply ignored those illustrations. This limits conclusions that can be drawn about differences between the illustrated text condition and the others. This could also explain why we excluded a substantial number of subjects because they did not meet minimum performance requirements. For every one participant that could be used in this dataset, three participants had to be excluded under these provisions.

Participant visual language fluency (as per the VLFI) could be another limitation to this study. We originally set out to include the VLFI to account for participant exposure to comics, as familiarity with the comic medium facilitates processing (Nakazawa, 2016). However, a vast majority of our participants fell below the threshold for “average” use. Therefore, it may be the case that benefits from the comic medium may only be found in those already fluent with it.

The length of time participants were exposed to each medium could also be a limiting factor for our design. In Hosler and Boomer (2011), instructors assigned one group readings from both a comic textbook and their traditional science textbook. Although students from this group improved their understanding by the end of the semester relative to a control group, the effect of the comic textbook could not be isolated from the traditional textbook. Our methods improved upon this design by assigning different mediums to different topics; however, any effect that may be present in the population is potentially too small to detect through one-shot learning. The minimal influence of each medium could be because the effects are compounded through repeated use over time. Our recommendation for future studies would be to expose participants to each medium over the course of several testing days and chart their progress. Likewise, Hosler and Boomer (2011) had an experimental control by not giving some students the science comic textbook. By exposing participants to all media and both question types in our study, potential effects may have been washed out. Future studies will want to consider randomly assigning one type of media to a participant and determine if a science comic effect occurs.

Finally, a third limitation of our design was the use of multiple-choice in a pre-post design. Although multiple-choice questions are the most common form used in education assessment, these types of questions increase noise in the data by adding in guessing. Future studies may also want to consider more open-ended assessments to establish prior knowledge and then use signal detection measures to test recognition memory for each level of mental representation (e.g., Schmalhofer & Glavanov, 1986). By using sentences that require distinct types of representations to recognize, we can better understand the media effect at the representational level rather than at higher levels like knowledge application.

In an alternative direction, future studies may want to place a greater emphasis on the influence cognitive load has on working memory and mental model updating. A review by Li, Antonenko, and Wang (2019) concluded that, despite the frequency of terms such as "working memory" or "cognitive load", relatively few studies have considered individual differences in working memory capacity in multimedia learning. Therefore, it may be worthwhile to focus on the online processing of information and chart changing cognitive processes as they occur in real time.

Comics appear to be successful in the development of reading ability, which is why future studies should focus more on elementary school students as their population of interest (Lin et al., 2015; Williams, 2008). College-aged participants may experience less benefit from a science comic versus an illustrated text because they have more experience with the latter. By the time they reach college, participants in this age cohort may have learned to adopt strategies that overcome any benefit one medium might have over another.

Finally, future studies may want to consider the influence each of these three mediums have on older populations. Older populations, on average, have reduced cognitive capabilities compared to younger adults, which influences the ability to consume information. Science comics, which appear to facilitate learning by reducing working memory load at encoding, could be a better delivery method for this population. Altogether, these results demonstrate that science comics are an alternative medium for multimedia instruction and that they show prospective benefit as a pedagogical tool.

Appendix A: Sample Explicit Questions

1. Germination is when...
    a. a plant begins to grow from a seed.
    b. a plant becomes infected.
    c. a plant begins to fruit.
    d. a plant sheds its seeds.

Please rate how confident you are in this answer. 1 2 3 4 5 6

2. The ___ branch(es) out from the taproot. They'll branch and branch until a dense system develops.
    a. lateral roots
    b. horizontal roots
    c. primary root
    d. vertical root

Please rate how confident you are in this answer. 1 2 3 4 5 6

3. Plants can sense gravity thanks to _______, cells that hold loose, heavy, starchy blobs.
    a. statocytes
    b. amylocytes
    c. glucocytes
    d. granulocytes

Please rate how confident you are in this answer. 1 2 3 4 5 6

4. __________ are a seedling's very first leaves, and they store its initial food supply like a lunch packed by its parents.

   a. Cotyledons

   b. Hypocotyls

   c. Radicles

   d. Hypercotyls

Please rate how confident you are in this answer. 1 2 3 4 5 6

5. Roots are pulled along by their ___________

   a. apical meristems

   b. auxin meristems

   c. floral meristems

   d. tropic meristems

Please rate how confident you are in this answer. 1 2 3 4 5 6

6. __________ is when plants grow toward sunlight.

   a. Phototropism

   b. Thermotropism

   c. Chemotropism

   d. Heliotropism

Please rate how confident you are in this answer. 1 2 3 4 5 6

Appendix B: Visual Language Fluency Index

Background Information Questionnaire Age________ Sex: M / F ID :____________________

1. Using the following scale, on average, how often per week do/did you…? (place a whole number in the square)

Never ---------------------------------Sometimes---------------------------------Always
1 2 3 4 5 6 7

	Currently (mark 1 – 7)	**While growing up (mark 1 – 7)**	**Which is your favorite? (mark with "X")**
…read text-only books for enjoyment			DO NOT MARK HERE
…watch movies			DO NOT MARK HERE
…watch cartoons/anime			DO NOT MARK HERE
…read comic books			
…read comic strips			
…read graphic novels			
…read Japanese comics (manga)			
…draw comics			

2. How would you rate your expertise with reading comics (of any sort)? (Mark "X" once in each row)

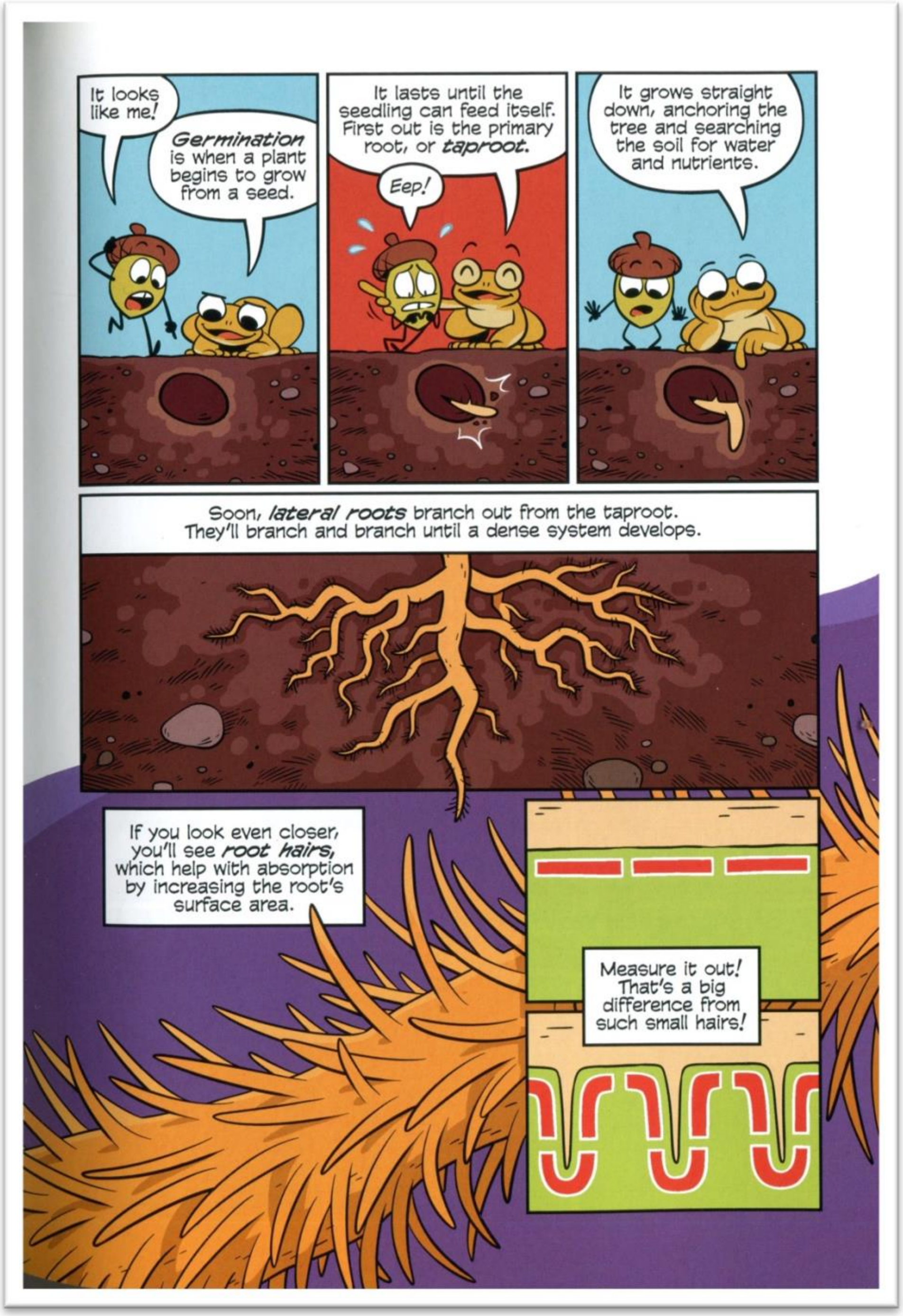
	Above average (5)	**Slightly above average (4)**	**Average (3)**	**Slightly below average (2)**	**Below average (1)**
Currently					
While growing up					

3. How would you rate your drawing ability? (Mark "X" once in each row)

	Above average (5)	**Slightly above average (4)**	**Average (3)**	**Slightly below average (2)**	**Below average (1)**
Currently					
While growing up					

4. How old were you when you began reading comics? ____________ Drawing comics? _____________

Appendix C: Sample Science Comic Format



Appendix D: Sample Illustrated Text Format

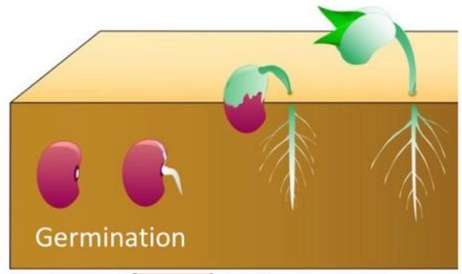
<u>WOODY</u>
"It looks like me!"

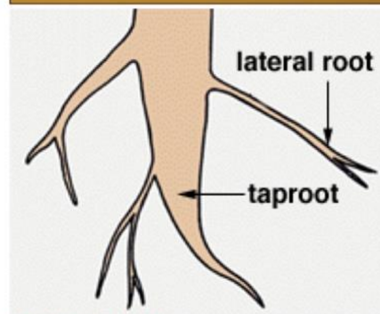
<u>FROGGY</u>
"***Germination*** is when a plant begins to grow from a seed. It lasts until the seedling can feed itself. First out is the primary root, or ***taproot***."

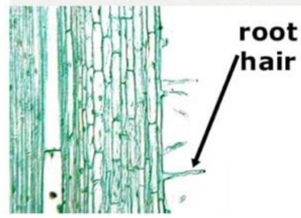
<u>WOODY</u>
"Eep!"

<u>FROGGY</u>
"It grows straight down, anchoring the tree and searching the soil for water and nutrients. Soon, ***lateral roots*** branch out from the taproot. They'll branch and branch until a defense system develops.

<u>FROGGY (cont'd)</u>
If you look even closer, you'll see ***root hairs***, which help with absorption by increasing the root's surface area. Measure it out! That's a big difference from such small hairs!"







Appendix E: Sample Text-Only Format

<u>WOODY</u>

It looks like me!

<u>FROGGY</u>

***Germination** is when a plant begins to grow from a seed. It lasts until the seedling can feed itself. First out is the primary root, or **taproot**.*

<u>WOODY</u>

Eep!

<u>FROGGY</u>

*It grows straight down, anchoring the tree and searching the soil for water and nutrients. Soon, **lateral roots** branch out from the taproot. They'll branch and branch until a defense system develops. If you look even closer, you'll see **root hairs**, which help with absorption by increasing the root's surface area. Measure it out! That's a big difference from such small hairs!*

Appendix F: Participant Interest Questionnaire

If you were to use [*Insert format*] to learn new information, how likely are you to this format again?

1	2	3	4	5
Very unlikely	Somewhat unlikely	Possibly	Somewhat likely	Very likely

If a friend wanted to learn new information, how likely are you to recommend [*Insert format*]?

1	2	3	4	5
Very unlikely	Somewhat unlikely	Possibly	Somewhat likely	Very likely

Appendix G: Sample Inferential Questions

1. Thigmotropism is a directional growth movement that comes from the Greek stem *thigma* meaning _____________.
    a. touch
    b. sunlight
    c. heat
    d. downward

Please rate how confident you are in this answer. 1 2 3 4 5 6

2. The (plant name), native to (location), overtakes the smaller plant (plant name) by the process known as ________________.
    a. apical dominance
    b. vertical subjugation
    c. auxin dominance
    d. Darwin's Law of Floral Dominance

Please rate how confident you are in this answer. 1 2 3 4 5 6

3. How do plants' roots maneuver around rocks and other objects underground?
    a. A chemical known as auxin groups on one side of the root and causes the plant to grow and turn towards the non-auxin side of the root.
    b. Heat from deeper layers of the Earth "turn-on" chemicals in the plants' roots, which drive them below the surface.
    c. Statocytes disperse along the root caps and sense their way around underground objects.
    d. Root hairs feel around for obstacles underground.

Please rate how confident you are in this answer. 1 2 3 4 5 6

4. How do root hairs increase a plant's absorption of nutrients?

    a. They add extra surface area to the root of a plant.
    b. Small entry points on their membrane widen when water is present.
    c. Root hairs secrete a mucus that absorbs more water.
    d. Root hairs use the sun to create more energy, which allows the plant to absorb more minerals.

Please rate how confident you are in this answer. 1 2 3 4 5 6

5. What happens to the lower shoots after the lead shoot is removed?

    a. They fight for superiority.
    b. They come together to make a new lead shoot.
    c. They die off soon after.
    d. They sprout new lead shoots.

Please rate how confident you are in this answer. 1 2 3 4 5 6

6. One characteristic used by botanists to classify flowering plants is to count the number of embryonic leaves present. They would most likely classify the number of ________________.

    a. cotyledons
    b. meristems
    c. taproots
    d. shoots

Please rate how confident you are in this answer. 1 2 3 4 5 6

References

Alexio, P., & Sumner, K. (2017). Memory for biopsychology material presented in comic book format. *Journal of Graphic Novels and Comics, 8*(1), 79-88. https://doi.org/10.1080/21504857.2016.1219957

Anglin, G. J., Vaez, H., & Cunningham, K. L. (2004). Visual representation and learning: The roles of static and animated graphics. In D. Jonassen (Ed.), *Handbook of research on educational communications and technology,* (2nd ed., pp. 865-916). Mahwah, NJ: Lawrence Erlbaum Associates.

Atkinson, R. C., & Shiffrin, R. M. (1968). Control processes in memory. *The Psychology of Learning and Motivation, 2,* 106.

Baddeley, A. D. (1986). *Working memory*. Oxford University Press.

Baddeley, A. D. (2001). Is working memory still working? *American Psychologist, 56*(11), 851-864. https://doi.org/10.1037/0003-066X.56.11.851

Baddeley, A. D., & Hitch, G. (1974). Working memory. In *Psychology of Learning and Motivation* (Vol. 8, pp. 47–89). Elsevier Science & Technology. https://doi.org/10.1016/S0079-7421(08)60452-1

Beymer, D., Orton, P. Z., & Russell, D. M. (2007). An eye tracking study of how pictures influence online reading. In C. Baranauskas, P. Palanque, J. Abascal, & S. Barbosa (Eds.), *Human-computer interaction – INTERACT 2007* (pp. 456-460). Springer. https://doi.org/10.1007/978-3-540-74800-7_41

Bongco, M. (2000). *Reading comics: Language, culture, and the concept of the superhero in comic books.* Garland Publishing.

Carney, R., & Levin, N. (2002). Pictorial illustrations still improve students' learning from text. *Educational Psychology Review, 14*(1), 5-26. https://doi.org/10.1023/A:1013176309260

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, *8*(4), 293-332. https://doi.org/10.1207/s1532690xci0804_2

Clark, J., & Paivio, M. (1991). Dual coding theory and education. *Educational Psychology Review*, *3*(3), 149-210. https://doi.org/10.1007/BF01320076

Cohen, L. S. (2020). *College Board.* The case for graphic novels in an AP classroom. Retrieved May 15, 2020, from https://apcentral.collegeboard.org/courses/ap-english-language-and-composition/classroom-resources/case-graphic-novels-ap-classroom

Cohn, N. (2013a). *The visual language of comics: Introduction to the structure and cognition of sequential images*. Bloomsbury.

Cohn, N., (2013b). Navigating comics: An empirical and theoretical approach to strategies of reading comic page layouts. *Frontiers in Psychology, 4*, 186. https://doi.org/10.3389/fpsyg.2013.00186.

Cohn, N. (2013c). Beyond speech balloons and thought bubbles: The integration of text and image. *Semiotica, 2013*(197), 35-63. https://doi.org/10.1515/sem-2013-0079

Cohn, N., (2014a). You're a good structure, Charlie Brown: The distribution of narrative categories in comic strips. *Cognitive Science, 38*(7), 1317–1359. https://doi.org/10.1111/cogs.12116.

Cohn, N. (2014b). The architecture of visual narrative comprehension: The interaction of narrative structure and page layout in understanding comics. *Frontiers in Psychology, 5*, 680. https://doi.org/10.3389/fpsyg.2014.00680

Cohn, N. (2014c). The Visual Language Fluency Index: A measure of "comic reading expertise." *Visual Language Lab: Resources*. www.visuallanguagelab.com/resources.html. First posted online April 2014.

Cohn, N. (2019). Your Brain on Comics: A Cognitive Model of Visual Narrative Comprehension. *Topics in Cognitive Science, 12*(1), 352-386. https://doi.org/10.1111/tops.12421

Cohn, N., & Campbell, H. (2015). Navigating comics II: Constraints on the reading order of page layouts. *Applied Cognitive Psychology*, *29*(2), 193-199. https://doi.org/10.1002/acp.3086

Cohn, N., Jackendoff, R., Holcomb, P. J., & Kuperberg, G. R. (2014). The grammar of visual narrative: Neural evidence for constituent structure in sequential image comprehension. *Neuropsychologia, 64*, 63–70. https://doi.org/10.1016/j.neuropsychologia.2014.09.018.

Cohn, N., & Kutas, M. (2015). Getting a cue before getting a clue: Event-related potentials to inference in visual narrative comprehension. *Neuropsychologia, 77*, 267-278. https://doi.org/10.1016/j.neuropsychologia.2015.08.026

Cohn, N., Paczynski, M., Jackendoff, R., Holcomb, P., & Kuperberg, G. (2012). (Pea)nuts and bolts of visual narrative: Structure and meaning in sequential image comprehension. *Cognitive Psychology, 65*(1), 1-38. https://doi.org/10.1016/j.cogpsych.2012.01.003

Damopolli, I., & Rahman, S. R. (2019). The effect of STAD learning model and science comics on cognitive students achievement. *Journal of Physics: Conference Series*, *1157*(2), 1-6. https://doi.org/10.1088/1742-6596/1157/2/022008

Eitel, A., Scheiter, K., & Schüler, A. (2013). How Inspecting a Picture Affects Processing of Text in Multimedia Learning. *Applied Cognitive Psychology*, *27*(4), 451–461. https://doi.org/10.1002/acp.2922

Farinella, M. (2018). Science comics' super powers. *American Scientist*, *106*(4), 218-221. https://doi.org/10.1511/2018.106.4.218

Gambrell, L., & Jawitz, P. (1993). Mental imagery, text illustrations, and children's story comprehension and recall. *Reading Research Quarterly*, *28*(3), 265-276. https://doi.org/10.2307/747998

Gehring, R. E., Toglia, M. P., & Kimble, G. A. (1976). Recognition memory for words and pictures at short and long retention intervals. *Memory & Cognition*, *4*(3), 256-260. https://doi.org/10.3758/BF03213172

Glenberg, A. M., & Langston, W. E. (1992). Comprehension of illustrated text: Pictures help to build mental models. *Journal of Memory and Language*, *31*(2), 129-151. https://doi.org/10.1016/0749-596X(92)90008-L

Green, M., & Myers, K. (2010). Graphic medicine: Use of comics in medical education and patient care. *BMJ: British Medical Journal (Online)*, *340*(7746), 574-577. https://doi.org/10.1136/bmj.c863

Gorman, M. (2003). *Getting graphic! Using graphic novels to promote literacy with preteens and teens*. Linworth.

Gurung, R. A. R. (2017). Predicting learning: Comparing an open educational resource and standard textbooks. *Scholarship of Teaching and Learning in Psychology*, *3*, 233–248.

Gyselinck, V. (1996). Illustrations et modèles mentaux dans la compréhension de textes [Illustrations and mental models in text comprehension]. *L'Année Psychologique, 96*, 495-516. https://doi.org/10.3406/psy.1996.28911

Gyselinck, V., & Tardieu, H. (1999). The role of illustrations in text comprehension: What, when, for whom, and why? In H. van Oostendorp, & S. R. Goldman (Eds.), The construction of mental representations during reading (pp. 195-218). Lawrence Erlbaum Associates. https://doi.org/10.4324/9781410603050

Hirsch, A. (2018). *Science Comics: Trees: Kings of the Forest*. First Second.

Hosler, J. (2008). *Optical allusions*. Active Synapse.

Hosler, J., & Boomer, K. B. (2011). Are comic books an effective way to engage nonmajors in learning and appreciating science? *CBE Life Sciences Education*, *10*(3), 309–317. https://doi.org/10.1187/cbe.10-07-0090

Jaeger, A. J., & Wiley, J. (2014). Do illustrations help or harm metacomprehension accuracy? *Learning and Instruction, 34*, 58-73. https://doi.org/10.1016/j.learninstruc.2014.08.002

Kintsch, W. (1994). The psychology of discourse processing. In M. A. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 721-739). Academic Press. https://doi.org/10.1016/B978-0-12-369374-7.X5000-7

Kintsch, E., & Kintsch, W. (1995). Strategies to promote active learning from text: Individual differences in background and knowledge. *Swiss Journal of Psychology, 54*, 141-151.

Knecht, P., & Najvarová, V. (2010). How do students rate textbooks? A review of research and ongoing challenges for textbook research and textbook production. *Journal of Educational Media, Memory & Society, 2*(1), 1-16. https://doi.org/10.3167/jemms.2010.020101

Koch, F. (2017). *Science Comics: Bats: Learning to Fly*. First Second.

Koenke, K. (1981). The careful use of comic books. *Reading Teacher, 34*, 592-595.

Landherr, L. J. T. (2016, April 28–30). *The production of science comics to improve undergraduate engineering*. Proceedings, American Society for Engineering Education, 2016 Northeast Section, Kingston, Rhode Island.

Levie, H. W., & Lentz, R. (1982). Effects of text illustrations: A review of research. *Educational Communication and Technology Journal*, *30*, 195–232. https://doi.org/10.1007/BF02765184

Lin, S. F. & Lin, H. S. (2016) Learning nanotechnology with texts and comics: The impacts on students of different achievement levels. *International Journal of Science Education, 38*(8), 1373-1391. https://doi.org/10.1080/09500693.2016.1191089

Lin, S. F., Lin, H. S., Lee, L., & Yore, L. D. (2015). Are science comics a good medium for science communication? The case for public learning of nanotechnology. *International Journal of Science Education, 5*(3), 276–294. https://doi.org/10.1080/21548455.2014.941040

Liu, Y., & Treagust, D.F. (2013) Content analysis of diagrams in secondary school science textbooks. In M. Khine (Ed.), *Critical Analysis of Science Textbooks* (pp. 287-300). Springer. https://doi.org/10.1007/978-94-007-4168-3_14

Magliano, J., Kopp, K., McNerney, M. W., Radvansky, G. A., & Zacks, J. M. (2012). Aging and perceived event structure as a function of modality. *Aging, Neuropsychology, and Cognition, 19*(1-2), 264-282. https://doi.org/10.1080/13825585.2011.633159

Magliano, J. P., Larson, A. M., Higgs, K., & Loschky, L. C. (2016). The relative roles of visuospatial and linguistic working memory systems in generating inferences during visual narrative comprehension. *Memory & Cognition, 44*(2), 207-219. https://doi.org/10.3758/s13421-015-0558-7.

Magliano, J. P., & Zacks, J. M. (2011). The impact of continuity editing in narrative film on event segmentation. *Cognitive Science, 35*(8), 1489-1517. https://doi.org/10.1111/j.1551-6709.2011.01202.x

Magner, U. I. E., Schwonke, R., Aleven, V., Popescu, O., Renkl, A. (2014). Triggering situational interest by decorative illustrations both fosters and hinders learning in computer-based learning environments. *Learning and Instruction, 29,* 141-152. https://doi.org/10.1016/j.learninstruc.2012.07.002

Mayer, R. E. (2009). *Multimedia learning*. (2nd ed.). Cambridge University Press.

Mayer, R. E., & Massa, L. (2003). Three facets of visual and verbal Learners: Cognitive ability, cognitive style, and learning preference. *Journal of Educational Psychology, 95*(4), 833-846. https://doi.org/10.1037/0022-0663.95.4.833

Mayo, C. M. (2011). Use of a popular comic strip character as a teaching tool in aphasia: The case for “Grandpa Jim.” *Perspectives on Issues in Higher Education*, *14,* 46–56. https://doi.org/10.1044/ihe14.2.46

McCloud, S. (1993). *Understanding comics: The invisible art*. Harper Collins.

McPherson, K. (2006). Graphic literacy. *Teacher Librarian, 33*(4), 67-69.

Molinari, G., & Tapiero, I. (2007). Integration of new domain-related states and events from texts and illustrations by subjects with high and low prior knowledge. *Learning and Instruction, 17*(3), 304-321. https://doi.org/10.1016/j.learninstruc.2007.02.005

Moreno, R. (2006). Does the modality principle hold for different media? A test of the method-affects-learning hypothesis. *Journal of Computer Assisted Learning, 22*(3), 149-158. https://doi.org/10.1111/j.1365-2729.2006.00170.x

Moreno, R., & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity effects. *Journal of Educational Psychology, 91*, 358–368. https://doi.org/10.1037/0022-0663.91.2.358

Moreno, R., & Mayer, R. E. (2000). Engaging students in active learning: The case for personalized multimedia messages. *Journal of Educational Psychology, 92*(4), 724-733. https://doi.org/10.1037/0022-0663.92.4.724

Morrow, D. G., Stine-Morrow, E. A. L., Leirer, V. O., Andrassy, J. M., & Kahn, J. (1997). The role of reader age and focus of attention in creating situation models from narratives. *Journal of Gerontology: Psychological Sciences, 52B*(2), P73–P80. https://doi.org/10.1093/geronb/52B.2.P73

Mosco, R. (2018). *Science Comics: Solar System: Our Place in Space*. First Second.

Nagata, R. (1999). Learning biochemistry through manga—helping students learn and remember, and making lectures more exciting. *Biochemical Education, 27*, 200-203. https://doi.org/10.1016/S0307-4412(99)00052-7

Nakazawa, J. (2016). Manga literacy and manga comprehension in Japanese children. In N. Cohn (Ed.), *The Visual Narrative Reader* (pp. 157-184). Bloomsbury.

Osaka, M., Yaoi, K., Minamoto, T., & Osaka, N. (2014). Serial changes of humor comprehension for four-frame comic Manga: An fMRI study. *Scientific Reports, 4*(1), 5828. https://doi.org/10.1038/srep05828

Özdemir, E. (2017). Humor in elementary science: Development and evaluation of comic strips about sound. *International Electronic Journal of Elementary Education, 9*(4), 837-850.

Paivio, A. (1986). *Mental representations: A dual coding approach* (Oxford psychology series; no. 9). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195066661.001.0001

Paivio, A., & Csapo, K. (1973). Picture superiority in free recall: Imagery or dual coding? *Cognitive Psychology, 5,* 176-206. https://doi.org/10.1016/0010-0285(73)90032-7

Paivio, A., Rogers, T. B., & Smythe, P. C. (1968). Why are pictures easier to recall than words? *Psychonomic Science, 11,* 137-138. https://doi.org/10.3758/BF03331011

Radvansky, G., Gerard, L., Zacks, R., & Hasher, L. (1990). Younger and older adults' use of mental models as representations for text materials. *Psychology and Aging, 5*, 209–214. https://doi.org/10.1037/0882-7974.5.2.209

Radvansky, G. A., & Curiel, J. M. (1998). Narrative comprehension and aging: The fate of completed goal information. *Psychology and Aging, 13*, 69–79. https://doi.org/10.1037/0882-7974.13.1.69

Rayner, K., Rotello, C. M., Stewart, A. J., Keir, J., & Duffy, S. A. (2001). Integrating text and pictorial information: Eye movements when looking at print advertisement. *Journal of Experimental Psychology: Applied, 7*(3), 219-226. https://doi.org/10.1037//1076-898x.7.3.219

Reed, M. K. (2016). *Science Comics: Dinosaurs: Fossils and Feathers*. First Second.

Rota, G., & Izquierdo, J. (2003). "Comics" as a tool for teaching biotechnology in primary schools. *Electronic Journal of Biotechnology, 6*(2), 85-89.

Sones, W. W. D. (1944). The comics and instructional method. *Journal of Educational Sociology* 18 (4), 232–240. https://doi.org/10.2307/2262696

Scheiter, K., Schuler, A., Gerjets, P., Huk, T., & Hesse, F. W. (2014). Extending multimedia research: How do prerequisite knowledge and reading comprehension affect learning from text and pictures. *Computers in Human Behavior, 31*, 73. https://doi.org/10.1016/j.chb.2013.09.022

Schnotz, W. (2014). Integrated model of text and picture comprehension. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed., pp. 72–103). http://dx.doi.org/10.1017/CBO9781139547369 .006

Schnotz, W., & Bannert, M. (2003). Construction and interference in learning from multiple representation. *Learning and Instruction, 13*, 141–156. http://dx.doi.org/10.1016/S0959-4752(02)00017-8

Schnotz, W., Ludewig, U., Ullrich, M., Horz, H., McElvany, N., & Baumert, J. (2014). Strategy shifts during learning from texts and pictures. *Journal of Educational Psychology, 106*(4), 974-989. https://doi.org/10.1037/a0037054

Schnotz, W., & Wagner, I. (2018). Construction and elaboration of mental models through strategic conjoint processing of text and pictures. *Journal of Educational Psychology, 110*(6), 850-863. https://doi.org/10.1037/edu0000246

Schwarz, G. E. (2002). Graphic novels for multiple literacies. *Journal of Adolescent & Adult Literacy*, *46*(3), 262-265.

Scott, M. (2018). *Science Comics: Robots and Drones: Past, Present, and Future*. First Second.

Short, J. C., Randolph-Seng, B., & McKenny, A. F. (2013). Graphic presentation: An empirical examination of the graphic novel approach to communicate business concepts. *Business Communication Quarterly*, *76*(3), 273–303. https://doi.org/10.1177/1080569913482574

Spiegel, A. N., McQuillan, J., Halpin, P., Matuk, C., & Diamond, J. (2013). Engaging teenagers with science through comics. *Research in Science Education*, *43*(6), 2309–2326. https://doi.org/10.1007/s11165-013-9358-x

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*, 257-285. https://doi.org/10.1207/s15516709cog1202_4

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction, 4,* 295-312. https://doi.org/10.1016/0959-4752(94)90003-5

Syma, C., Weiner, R., & Ebrary, Inc. (2013). *Graphic novels and comics in the classroom essays on the educational power of sequential art*. McFarland & Company.

Tatalovic, M. (2009). Science comics as tools for science education and communication: A brief, exploratory study. *Journal of Science Communication*, *8*(4), 1–17. https://doi.org/10.22323/2.08040202

Tribull, C. (2017). Sequential science: A guide to communication through comics. *Annals of the Entomological Society of America, 110*(5), 457-466. https://doi.org/10.1093/aesa/sax046

van Dijk, T., & Kintsch, W. (1983). *Strategies of Discourse Comprehension*. Academic Press.

Versaci, R. (2001). How comic books can change the way our students see literature: One teacher's perspective. *English Journal, 91*(2), 61-67.

Viola, J. (2018). *Science Comics: Polar Bears: Survival on the Ice*. First Second.

Wang, Z., Wang, S., Farinella, M., Murray-Rust, D., Henry Riche, N., & Bach, B. (2019, May 4–5). *Comparing Effectiveness and Engagement of Data Comics and Infographics*.

Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, Glasgow, Scotland, UK. https://doi.org/10.1145/3290605.3300483

Williams, R. (2008). Image, text, and story: Comics and graphic novels in the classroom. *Art Education*, *61*(6), 13–19.

Williams, I. C. M. (2012). Graphic medicine: Comics as medical narrative. *Journal of Medical Humanities*, *38*(1), 21. https://doi.org/10.1136/medhum-2011-010093

Yang, G. (2008). Graphic novels in the classroom. *Language Arts, 85*(3), 185-192.

Zwaan, R. A., & Radvansky, G. A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin, 123*(2), 162-185. https://doi.org/10.1037/0033-2909.123.2.162

Curriculum Vitae

JACKSON S. PELZNER
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EDUCATION
Ph.D., Experimental Psychology with Cognitive emphasis, (Expected) 2024, University of Nevada, Las Vegas
M.A., Experimental Psychology with Cognitive emphasis, 2023, University of Nevada, Las Vegas
M.S., Applied Psychological Science with Research emphasis, 2016, Pacific University, Hillsboro, OR
B.Sc., Psychology, 2013, Acadia University, Wolfville, NS, Canada

PROFESSIONAL EXPERIENCE
Doctoral Student Researcher
Human Memory Lab
University of Nevada, Las Vegas
06/20 – Present (20 hrs per week; excludes summers)
Supervisor: Dr. Colleen Parks

- Designed and programmed psychological studies examining episodic memory, mental representations, and music cognition
- Used data analytics and computational modeling to understand human recognition across visual and auditory domains
- Developed research proposal presented at a national conference
- Led weekly lab meetings with graduate students and undergraduate research assistants to critically analyze and discuss current research in our field
- Mentored undergraduate research assistants
- Worked on collaborative project examining foundations of recognition memory using naturalistic stimuli

Part-Time Instructor
Psychology Department
University of Nevada, Las Vegas
08/19/20 – Present (20 hrs per week)

- Taught 12 remote and online undergraduate courses in general psychology (PSY 101)
- Prepared and delivered online lectures on a broad range of topics in psychology
- Led productive, engaging classroom discussions
- Implemented fair and reasonable grading procedures and exams that accurately reflect course content

Repperger Intern
Air Force Research Laboratory
711 Human Performance Wing
Airman System's Directorate
Adaptive Warfighter Interfaces, Mission Analytics Branch (711HPW/RHWAR)

2255 H St, Bldg 248, WPAFB, OH 45433-7022
06/07/21 – 08/13/21 (40 hrs per week)
Supervisor: Dr. Kathleen Larson

- Collaborated on research projects aimed at understanding the psychological foundations of deceptive, malignant information
- Created data visualizations in R for summary briefings
- Programmed data analysis algorithm in R
- Mentored undergraduate USAFA cadets

Repperger Intern
Air Force Research Laboratory
711 Human Performance Wing
Airman System's Directorate
Adaptive Warfighter Interfaces, Cognitive Science, Models, and Agents Branch (711HPW/RHWM)
2620 Q Street, WPAFB, OH 45433
06/08/20 – 08/14/20 (20 hrs per week)
Supervisor: Dr. Christopher Stevens

- Worked on collaborative project understanding the effects of vigilance and fatigue on performance.
- Designed and programmed fatigue module for cognitive model.
- Presented discoveries from summer project to branch directors.

Doctoral Student Researcher
Reasoning and Memory Lab
University of Nevada, Las Vegas
08/18 – 05/20 (20 hrs per week; excludes summers)
Supervisor: Dr. David Copeland

- Designed independent psychological studies examining cognitive topics such as event cognition, mental models, learning, and visual languages.
- Conducted a first-year project testing the *Von Restorff effect* with musical and emotional stimuli that was later presented at a regional conference.

Laboratory Manager
Reasoning and Memory Lab
University of Nevada, Las Vegas
08/18 – 05/20 (20 hrs per week)
Supervisor: Dr. David Copeland

- Oversaw administrative lab duties including coordinating schedules, updating computers, and writing IRB protocols.
- Trained and supervised research assistants (~7 research assistants per semester).
- Mentored undergraduate students on research design, analysis, and dissemination.

Lead Moderator
Omedia Interactive

04/17-05/17 & 08/17-10/17 (~10 hrs per week)
Supervisor: Jim Olsen

- Worked on project to code emotion-related behaviors in the development of emotion-recognition software for autonomous vehicles and educational practice.
    - Assisted the principal investigator in day-to-day project activities
    - Responsible for transport and protection of computer hardware
    - Updated computer files used for data collection
- Worked on a project to determine the optimal hardware/software configuration for marketing new processors for virtual reality use.
    - Helped design and implement study protocols
    - Assisted with data collection projects
    - Facilitated participation discussion sessions

SPECIALIZED TRAINING

Graduate Certificate in Quantitative Psychology

SKILLS

Statistics Software:

SPSS	*Proficient*
R	*Intermediate*
SQL	*Beginner*

Programming:

E-Prime	*Intermediate*
Java	*Beginner*
Max8	*Beginner*
PsychoPy	*Beginner*

Advanced Statistical Techniques:

Multiple Regression
Multivariate Statistics

AWARDS

Science, Mathematics, and Research for Transformation (SMART) Scholarship for Service Fellowship Semi-Finalist, Department of Defense (2022)
Summer Doctoral Research Fellowship, UNLV ($7,000, 2022)
Patricia Sastaunik Scholarship, UNLV ($2,500, 2022)
SMART Scholarship for Service Fellowship Semi-Finalist, Department of Defense (2021)
College of Liberal Arts Ph.D. Student Summer Research Stipend, UNLV ($2,500, 2019)
Graduate College Recruitment Scholarship, UNLV ($500, 2018)

MEMEBERSHIP IN PROFESSIONAL SOCIETIES

Association for Psychological Science
Society for the Teaching of Psychology
Psychonomic Society

SERVICE

- 2021-2022: *Committee member*, Graduate Student Teaching Association, American Psychological Association (Div. 2)
- 2019-2020: *Committee officer*, Experimental Student Committee, University of Nevada, Las Vegas

PUBLICATIONS AND PRESENTATIONS

Pelzner, J.S. (2021, August 5-6) *Understanding the Cognitive Foundations of Misinformation in an Information Environment* [Research presentation]. Repperger Intern Research Summit, Wright-Patterson AFB.

Pelzner, J.S. (2021, May 26-27). *Dissociable similarity gradients in a test of melody recognition* [Research proposal poster presentation]. Association for Psychological Science, Virtual.

Ridgway, W.B., Aquino, E.A., **Pelzner, J.S.,** Mansour, J.K., Parks, C.M., & Copeland, D.E. (2021). *The effects of stress on eyewitness recall: A field study* [Manuscript in preparation]. Department of Psychology, University of Nevada Las Vegas.

Ridgway, W.B., Aquino, E.A., Mann, B.A., **Pelzner, J.S.**, Parks, C.M., & Copeland, D.E. (2020, November 19- 22). *Eyewitness recall and identification: Effects of stress in an extreme haunt and a haunted house* [Poster presentation]. Psychonomic Society, Virtual.

Pelzner, J.S. (2020, August 4-5) *Building a Cognitive Model to Simulate Human Workload and Fatigue* [Research presentation]. Repperger Intern Research Summit, Virtual.

Pelzner, J.S. (2019, April 25-28). *Joint effects of music and emotion on memory*. [Poster presentation]. Western Psychological Association, Pasadena, CA.