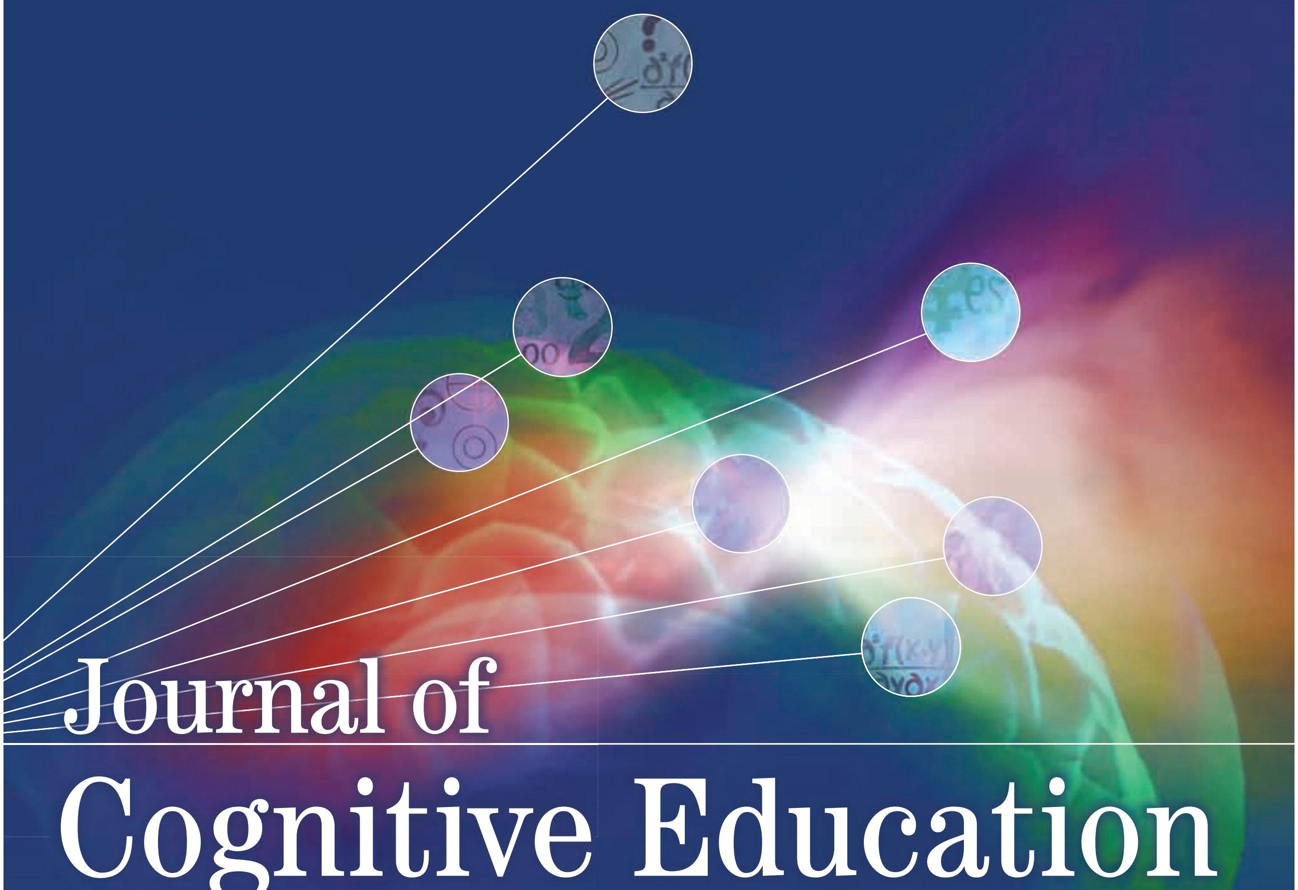
Official Publication of the International Association for Cognitive Education and Psychology

www.iacep-coged.org



Journal of Cognitive Education and Psychology

With the Compliments of Springer Publishing Company, LLC

SPRINGER PUBLISHING COMPANY

www.springerpub.com/jcep

Journal of Cognitive Education and Psychology
Volume 11, Number 2, 2012

Comic Cognition: Exploring the Potential Cognitive Impacts of Science Comics

Benjamin D. Jee
Florencia K. Anggoro
College of the Holy Cross, Worcester, Massachusetts

Increasing people's interest and involvement in science is a growing concern in education. Although many researchers and educators seek innovations for classroom instruction, much could be gained by harnessing the activities that people perform at their leisure. Although new media are constantly emerging, comic book reading remains a popular activity for children and adults. Recently, there has been an explosive increase in the creation of educational comic books, including many about science. This rapid increase in science comics far outstrips our understanding of how comics impact people's beliefs and interests in science. In this theoretical article, we draw on research from cognitive science and education to discuss heretofore unexplored cognitive impacts of science comics. We propose several ways in which learning could be enhanced or impaired through reading science comics and discuss several broader issues related to the use of comic books in education, including individual differences and informal learning.

Keywords: science comics; science learning; comic books; cognition; education; informal learning

A major educational initiative in North America and worldwide is to increase participation and performance in science. It is thus important to examine ways to get students interested and involved. One potentially powerful way to expose students to scientific ideas is through mediums that they already enjoy and use. There is no question that new media such as cell phone applications and video games are popular with children and teenagers. However, some forms of media that have existed for decades have also remained popular. Comic books[1] are one such medium. In a survey of leisure reading behavior involving more than 1,300 American fifth through eighth graders, Hughes-Hassell and Rodge (2007) found that 44% of students read comic books as part of their leisure reading, compared to 30% who reported reading books. The fact that many students enjoy reading comics in their spare time is encouraging and raises the possibility that science-related comic books could reach and influence a vast number of children. Indeed, several science-related comic books have been created with this goal in mind (Tatalovic, 2009).

http://dx.doi.org/10.1891/1945-8959.11.2.196

The genre of comics for which science education is a primary goal—what we will refer to as *science comics*[2]—is the primary focus of this theoretical article. In this article we discuss cognitive factors related to learning from science comics. Because there has been such little research on learning from science comics and none that specifically addresses various cognitive impacts, we aim to achieve our goal by drawing on work related to general mechanisms of knowledge acquisition and transfer, learning from media (including text, diagrams, and mixed media), and judging one's own learning from text (metacomprehension). By highlighting some ways in which science comics could help as well as hinder learning, we hope to inform researchers, creators of science comics, as well as educators who may include science comics in their curricula and lessons.

COMICS IN SCIENCE EDUCATION

It may seem ironic for comics to be considered as a medium for science education. Indeed, comics are stigmatized as being antithetical to scholarly activity. Hutchinson (1949) observed that teachers criticized comics for their improper language, for bringing levity to serious topics, for making learning "too easy," and for taking away time from other more important activities. It is possible that some teachers' attitudes have not changed much in the 60 or more years since this study (e.g., Millard & Marsh, 2001). Yet, such attitudes are misplaced. Although some comics may be used purely for entertainment, there are a number of comics that could enhance learning and interest in academic topics. Graphic novels, such as *Clan Apis* (Hosler, 2000), a comic about the behavior of bees, and *Dignifying Science* (Ottaviani, 2003), a comic about famous women in science, are a far cry from the newspaper comic strips that may come to mind when the term comics is used (see Tatalovic, 2009, for further examples). In fact, some comic books, such as Jay Hosler's (2008) *Optical Allusions*, may provide an appealing alternative to standard science textbooks (Hosler & Boomer, 2011). There are also many educationally relevant graphic novels outside of the science realm. Several literary classics, including works by Shakespeare and Edgar Allen Poe, have been translated into graphic novels; and original works of fiction, such as Art Spiegelman's (1986) Pulitzer-winning *Maus*, have appealed to readers, critics, and educators alike. Even government agencies are using comics to communicate ideas. For example, White House advisor Jonathan Gruber recently announced plans to create a graphic novel about health care reform (LeBlanc, 2011). Comics take many forms (see Note 1), and this flexibility underscores the great potential of comics for education.

At present, the genre of science comics is rapidly expanding. It is now common to find science comics in classrooms, libraries, and other educational contexts. To provide some popular examples, the *Max Axiom* series—a comic about a science teacher/super scientist—now has 24 volumes spanning a variety of science topics, including global warming, states of matter, and cell life. Concept Cartoons (www.conceptcartoons.com) are also becoming widely used in the classroom. These single-panel cartoons (not a comic per se; see Note 1) may be an effective way to present students with scientific ideas and problems (see Keogh & Naylor, 1999). A series of comic books called *World of Viruses* (www.worldofviruses.unl.edu) aims to spark children and teenagers' interest in the microbiological basis of viruses through a blend of fictional and nonfictional storytelling. In addition, the Maryland State Department of Education recently launched an initiative to support the use of comics for elementary, secondary, adult, and corrections classrooms (www.marylandpublicschools.org/MSDE/programs/recognition-partnerships/mcbi/overview.htm). This program has recently included Ottaviani's (2003) *Dignifying Science* series in its curriculum, extending this initiative to science education as well as literacy.

Science comics are also becoming popular outside of the classroom, especially for educating patients and their families about health problems. For example, the *Medikidz* series attempts to educate children, particularly young patients themselves, about diseases such as leukemia and diabetes. Medikidz comics have sold over one million copies and have been published in 18 languages ("The Medikidz Story," n.d.). For more adult audiences, Brian Fies's (2006) acclaimed graphic novel *Mom's Cancer* delves into the author's experiences as his mother battles lung cancer. Green and Myers (2010) recently praised the use of such comics for both patient care and medical education. Also related to medical education, Park, Kim, and Chung (2011) describe their initiative to create comic strips for teaching anatomy to college students. These authors use humor and a variety of visualizations in these comics in an attempt to further engage students.

At this point in time, empirical research lags far behind the expanding use of new media in education (Dede, 2009; Greenfield, 2009). Although several articles have discussed the potential benefits of science comics, there have been few systematic studies demonstrating their effectiveness (Hosler & Boomer, 2011). Rota and Izquierdo (2003) observed that children who were exposed to science comics about agriculture, biology, and technology seemed to understand the science better, although these observations were largely anecdotal. Weitkamp and Burnet (2007) described a comic that illustrates chemistry concepts through a series of pranks played out by the comic's main character, the *Chemedian*. The authors found that at least some children understood the science principles from the comic, but because learning was assessed in a group setting, it is unclear whether this learning was representative of most children. Olson (2008) found that lessons that incorporated comics increased learning for some specific science concepts and that students generally enjoyed working with the comics. Likewise, Özdemir (2010) found that sixth grade students who received a lesson on matter and heat supplemented with comics achieved higher scores on several tests of understanding compared to students who were not provided with the comics. Finally, Hosler and Boomer (2011) report on a recent study involving the use of the science comic book *Optical Allusions* (Hosler, 2008) in a nonmajors biology class. The students who read the comic book, especially those with low initial knowledge, increased their performance on a test of understanding. Moreover, students' attitudes about biology increased with their attitudes about the comic, suggesting that the comic may have engaged some students with otherwise low interests in science.

The growing volume of research on learning from science comics is encouraging. Yet, much work remains to be done, especially regarding the immediate and long-term effects of science comics on people's understanding of and reasoning about scientific phenomena. Science learning involves several unique challenges, including the revision of potentially erroneous intuitive beliefs (e.g., Vosniadou & Brewer, 1992), thinking about invisible entities (Duschl, Schweingruber, & Shouse, 2007), and spatial thinking (Downs & DeSouza, 2006). Although some research suggests some positive effects on learning, the impact of science comics on these cognitive processes is presently unknown. What aspects of science learning could be enhanced through reading comics? What obstacles arise? How could science comics be altered to amplify the strengths and overcome the obstacles?

COGNITIVE IMPACTS OF LEARNING SCIENCE FROM COMICS

In the following sections, we draw on research from psychology and education to discuss the potential cognitive impacts of science comics and to raise several issues that are ripe for future study. The sections are motivated by a consideration of the cognitive processes involved in science learning, including general learning mechanisms, multimedia learning, and metacognition.

Comics Make Scientific Concepts and Principles More Concrete

There is mounting evidence that even abstract knowledge may depend on perceptually based representations (Barsalou, 1999; Glenberg & Kaschak, 2002). When bringing a concept to mind or forming a mental representation of an object or scene, perceptual and motor knowledge becomes activated in the mind (Barsalou, 1999). Thus, providing the learner with a rich perceptual experience with which they can ground their understanding may enhance science learning. These rich visualizations (together with the text and dialogue) in science comics may be especially useful when scientific objects are unavailable.

A related concern in science education is how to teach students about phenomena that are beyond human perception, such as microscale chemical and biological processes and macroscale geological and astronomical processes. Many developmental scientists have argued that children are unable to learn about objects that are invisible and cannot be physically manipulated (Duschl et al., 2007; Krajcik, McNeill, & Reiser, 2008). However, some research has found that children can learn about these entities when the entities are visually modeled and the relationship between the invisible and visible is made transparent (Stein, Hernandez, & Anggoro, 2010). Visual models can clarify and disambiguate physical events and when used properly can benefit experts as well as novices (Tversky, Heiser, Mackenzie, Lozano, & Morrison, 2008). Comics may provide another effective way to visually model scientific phenomena. It is common for comics to express shifts in scale (McCloud, 1993), for example, by zooming in and out from frame to frame. Objects and events that are invisible to the naked eye are thus illustrated, described, and explicitly related to objects and events at the same or different scales.

Comics Capitalize on the Benefits of Spatially Contiguous Text and Images

Comic books present a story by integrating two mediums: words and pictures. This is not unique to comics; most textbook diagrams include an image along with labels and/or a caption. Yet, the conventional way in which comics integrate words and images may be especially powerful for learning. Research by Mayer and colleagues (e.g., Mayer, 2003; Mayer, Steinhoff, Bower, & Mars, 1995; Moreno & Mayer, 1999) has found that embedding text in an image can lead to better understanding than when text and image are separated—the *spatial contiguity effect*. The spatial contiguity effect is more pronounced when the text is placed next to the part of the image being described as opposed to below the image (e.g., Moreno & Mayer, 1999). In a meta-analysis, Ginns (2006) found that increasing the spatial contiguity of written and pictorial elements greatly improved learning, especially for complex materials.

In comic books, text is integrated with images in a variety of ways. Text can be used to represent a narrator's commentary (see Figure 1, panel a). Although this is similar to a caption, narration is often placed within the comic image rather than below it. Text appearing in word and thought bubbles conveys a character's speech and unspoken thoughts (see Figure 1, panel b; the thought bubbles resemble clouds). These bubbles are conventionally linked to the speaker (or thinker) by tapering the bubble toward the speaker. In addition, words for sound effects ("smash," "kaboom," etc.) are embedded within an image to provide impact (see Figure 1, panel c). As Mayer (2003) suggests, spatial contiguity could facilitate active learning

a b c

FIGURE 1. Three ways in which comics integrate text with images: (a) narration, (b) speech and thought bubbles, (c) sound effects. Original artwork by Jack Butler.

by making it easier to integrate text and images. Also, spatial contiguity can disambiguate the mapping between text and image components. Indeed, labels in scientific diagrams are especially helpful when placed in close proximity to the particular elements of the image that they refer to (Mayer et al., 1995).

Comics Invoke Schemas That Influence Comprehension

Unlike typical teaching materials, comics have a narrative as opposed to an expository structure. As a reader attempts to comprehend a narrative, they form a mental representation of the characters, settings, actions, and events that are depicted in the words and images known as a *situation model* (van Dijk & Kintsch, 1983). Constructing a situation model involves schematic knowledge structures, or *schemas*, that contain placeholders for new information and support inference making (Schank & Abelson, 1977). For example, a person may draw on schematic knowledge to infer a character's goals and motives, the cause of an event, and the potential impact of an event on other characters (Graesser, Singer, & Trabasso, 1994).

The narrative structure of comics could make scientific material easier to comprehend. This is mainly because the content and structure of narratives is similar to our everyday experiences (Graesser, León, & Otero, 2002). For example, the comic *Clan Apis* (Hosler, 2000) follows the exploits of a honeybee named Nyuki as she learns about hive society from her friends and family. Schemas for similar types of events can help the reader fill in gaps in their understanding, leading to a more coherent situation model (Graesser et al., 1994). Infusing science lessons with narrative elements, such as anecdotes, can likewise benefit student understanding (Martin & Brouwer, 1991).

One risk of schema-based inferences is that people may draw incorrect inferences and misremember a story's content. Bartlett's (1932) seminal research on schemas found that Westerners' retellings of a Native American folktale were often distorted to conform to Western storytelling conventions. These retellings often omitted details that were inconsistent with Western schemas and inserted schema-consistent information. Inaccurate insertions—*schema intrusions*—are common when recalling familiar narratives (e.g., Bower, Black, & Turner, 1979). Thus, there is a risk that comic readers will make scientifically incorrect assumptions based on their prior schematic knowledge.

Comics Can Involve Personification of Nonhuman Entities

Nonhuman entities are often represented as human-like characters in science comics. For example, several comics in the *World of Viruses* series portray a virus as the protagonist. In *The Curse of the Tree-man* (Powell, Floyd, Rubinstein, & Beachler, 2009), a story about human papilloma virus (HPV) infection is told from the perspective of HPV, personified by the character HPV Girl. One consequence of personification is that readers may better relate to the characters, possibly forming an emotional attachment to them. This connection to a character could motivate readers to devote more time and cognitive resources to understanding a story. Also, encoding information by relating it to oneself (i.e., self-reference) has been shown to produce stronger, more resilient memories (Symons & Johnson, 1997). If the characters are not relatable, however, motivation may be lost and self-reference may not be possible. Unrelatable characters may also reinforce negative stereotypes about science.[3] To appeal to a diverse audience of readers, several science comics have portrayed characters (including scientists) as diverse in terms of race (e.g., *Max Axiom*) and gender (e.g., *Dignifying Science*). This diversity of characters may help these comics appeal to a wide range of readers and play a role in breaking down stereotypes, such as associating white males with the category "scientist."

Another potential consequence of personification is that children may be more likely to use their knowledge of humans to reason about biological entities (Carey, 1985; Hatano & Inagaki, 1997). Similar to schema-based inference, knowledge of humans provides a conceptual framework for learning about some new entity. For example, in *The Curse of the Tree-man*, personification of HPV may encourage readers to infer that viruses are simply acting on their own biological imperatives. This sort of intention-based understanding may support later reasoning with scientific schemas and mechanistic rather than intentional causes (Hatano & Inagaki, 1997).

Personification could also have unintended consequences. When people lack knowledge about scientific entities, they may overextend their anthropomorphic reasoning (Epley, Waytz, & Cacioppo, 2007). For example, readers may place characters into moral categories and assign subjective values to these characters. In the case of the *World of Viruses* series, telling the story from the perspective of a virus could encourage readers to view the virus as the "hero." This could lead them to misunderstand the actions of the body's immune system in fighting the virus or perhaps even the health-related consequences of infection. In clinical interviews with people reading the *World of Viruses* series, Matuk (2010) found that children sometimes mistook immune cells for "bad guys," perhaps because they applied a morally loaded prior narrative.

Comics Could Influence Metacognitive Judgments About Science Understanding

A final cognitive impact to consider is the influence of science comics on people's beliefs about their own learning. People's ability to judge their own level of comprehension—*metacomprehension accuracy*—is generally quite poor (e.g., Maki, 1998). Whereas students ought to base such judgments on the content and coherence of their situation model, they instead rely on invalid cues such as familiarity with the topic, ease of processing the text, and even the length of the text (Thiede, Griffin, Wiley, & Anderson, 2010). This may leave the reader unaware of the topics that were poorly understood and that should be the focus of future study efforts.

Although prior research on metacomprehension accuracy has not involved comic books, comic book reading may be especially likely to promote a false sense of understanding. For one, comic books tend to be easy to process, which can lead the reader to overestimate what they learned (Thiede et al., 2010). Another concern with comic books is that readers may confuse their knowledge of the narrative with their understanding of the science content. Although the storyline may have been well understood, details about scientific entities and processes may have been lost on the reader. This could steer comic book readers away from future opportunities to learn, because readers would mistakenly judge their understanding to be adequate. Since one intention of science comics is to entertain and motivate science interest, it is important to consider whether such metacognitive impacts exist, and, if so, how to overcome them.

SUMMARY

Research from psychology and education suggests several ways that science comics could influence cognition and learning. Table 1 summarizes the potential costs and benefits of learning science from comics that we discussed. This is not intended to be a comprehensive list but rather a list of some of the primary issues that come to light when science comic reading is considered from a cognitive perspective. Also, as mentioned earlier, the comic book medium is extremely flexible. These benefits and costs are sure to vary depending on the content of a particular comic, the characteristics of the reader, and how the comic is used.

Broader Educational Issues Concerning Science Comics

In addition to the impacts on cognition and learning discussed earlier, there are some broader issues related to the use of comics for science education. One issue concerns the effectiveness of science comics compared to other forms of media. Another important consideration is how comics affect learning for different individuals. The third issue involves understanding the larger context in which science comics are used. In the following section, we consider

TABLE 1. Summary of the Potential Cognitive Impacts of Learning Science From Comics

Potential cognitive benefits
1. Visual models make scientific concepts more concrete and accessible. 2. Spatial contiguity makes it easier to integrate text and images. 3. Narrative structure could make scientific material easier to comprehend. 4. Relatable characters could increase cognitive effort and encoding of information via self-reference. 5. Personification of nonhuman entities could support conceptual change from psychological to mechanistic causal reasoning.
Potential cognitive costs
1. Narrative structure could lead to schema-consistent, but scientifically incorrect inferences. 2. Unrelatable characters could decrease cognitive effort and reinforce stereotypes. 3. Personification could lead to unwanted moral attributions to nonhuman entities. 4. Ease of processing may promote a false sense of understanding.

these issues by focusing on several topics: how learning from static images compares to learning from other visual mediums (particularly animations), how individual differences in knowledge and cognition could influence learning from comics, and issues related to the informal nature of learning from comics.

Learning From Static Versus Dynamic Images. Several studies have compared how viewing static images versus dynamic animations affects learning. Intuitively, animations have several advantages over static images—they contain more information, they can show a process unfold in real time, etc. Höffler and Leutner (2007) conducted a meta-analysis and found that, indeed, animations generally led to better learning outcomes than static images. This effect was especially pronounced for video-based as opposed to computer-generated animations and for domains that involved procedural-motor learning.

Although the meta-analytic findings support an overall advantage for animation-based learning, a remaining question is when, if ever, static images are superior for learning. Several studies have found that learning outcomes from static images equal or exceed those from animations (e.g., Mayer et al., 1995; Tversky, Bauer-Morrison, & Bétrancourt, 2002). It is unclear at this point what distinguishes these studies from research that has found the opposite result. Mayer et al. (1995) suggested that static images support the types of effortful processing, such as self-explanation and mental imagery, that lead to better, more robust memory representations. Thus, images that engage this deeper level of processing in the learner may be especially effective. Comics are particularly engaging for many children and adults and may thus invoke a deeper level of cognitive processing. In addition, animations may be ineffective if the learner does not know what to pay attention to (Mayer et al., 1995; Tversky et al., 2002). Static images can be compared side-by-side, which can guide attention to important commonalities and differences (Gentner & Markman, 1994). It is also relevant that comic book images are unlike those found in science textbooks and that comics contain a greater concentration of images than the typical materials used in educational research. Thus, it is premature to evaluate the pedagogical merit of comics based on the prior findings that have not involved comics specifically, such as Höffler and Leutner's (2007) meta-analysis. Further research comparing comic books with animations and other forms of static images would be informative.

Individual Differences in Learning From Comics. Just as narrative schemas are likely to affect learning, familiarity with the specific type of storytelling found in comics could be influential. In addition, the visual conventions used in comics—the way that the panes are laid out on a page, the arrangement of word bubbles in a dialogue, the symbols used to reflect action, and so forth—may be more familiar to some readers than to others. If the reader has to devote cognitive resources to decoding the meaning of these basic elements, then they will have fewer resources to devote to comprehension (Sweller, 1994). Moreover, comprehension may be lost if the conventions are misunderstood. For example, Japanese manga will not make sense if read from left to right since the panes are ordered from right to left. It would be valuable to explore how knowledge of the comic genre itself affects learning. A reasonable expectation is that such knowledge may be confounded with gender, with boys being more familiar than girls for the conventions employed in comics.

Another factor that may affect learning from science-related comics is background knowledge in the scientific domain. People with low prior knowledge may benefit more from materials that depict or describe scientific entities and processes in full detail (McNamara, Kintsch, Songer, & Kintsch, 1996). Such comics could come with a cost, though.

The more closely a comic approximates a textbook, the less interested people may be in reading it.

There is also mounting evidence that spatial thinking skills in general are a vital contributor to student success in science, technology, engineering, and mathematics (STEM; Downs & DeSouza, 2006). Yet, children and adults vary in their ability to think spatially (e.g., Casey, Nuttall, Pezaris, & Benbow, 1995; Estes, 1998). It is of interest how individual differences in spatial thinking might contribute to science learning from comics. Higher spatial ability may lead to greater learning from science comics; this appears consistent with much prior work. However, the pervasive images in comics may compensate for low spatial ability in which case spatial ability will not predict learning outcomes. If the latter is the case, then comics could facilitate science learning for students who may otherwise struggle and lose interest.

In addition to being appropriate in terms of the reader's level of comic reading experience, background knowledge, and spatial skills, the comic must also be age-appropriate in terms of important qualities such as storyline, characters, and humor. Some science comics, such as the Medikidz series, are clearly directed at younger audiences with these factors in mind.

The Informal Nature of Learning From Comics. Informal learning experiences often provide a foundation for more formal learning (Bell, Lewenstein, Shouse, & Feder, 2009; Greenfield, 2009). In everyday settings, learners do not rely on an authority figure to provide them with new information and motivate them to learn. The learner is generally free to direct their energy and attention for as much time as they wish. There is relatively less money and time invested in such activities. This freedom and distinctiveness of experience could make informal learning more engaging, enjoyable, and memorable. These qualities of informal learning may apply to science comic reading outside of the classroom.

The majority of research on informal learning has centered on museums, science centers, and similar institutions. Yet, as Falk and Dierking (2010) point out, children and adults engage in informal science learning in a variety of ways, including hobbies (e.g., star gazing), researching health problems, and investigating natural disasters. In addition, people have access to many different sources of information, such as books, magazines, and websites, often with little effort and great immediacy. The rapid pace of technological innovation far exceeds that of learning research. For example, many comic books are now available in digital format and can be read on portable electronic devices, such as an iPad or a smart phone.

Technological innovations also permit a greater deal of interactivity with media. One way in which people may interact with science comics is by modifying, combining, and extending existing content or creating new comics altogether. For example, the comic authoring software Comic Life (www.plasq.com) was created to streamline the process of comic creation by providing a menu of layouts, images, and text options (Naylor & Keogh, 1999). In his book, *Manga High*, Bitz (2009) discusses the many ways in which students in an urban high school benefitted from creating comics about personally relevant experiences in their lives. In particular, these students were forced to think critically about the content of their stories because of the high level of planning and commitment required to create stories in comic format. Olson (2008) found complementary evidence for the benefits of creating comics about scientific principles.

How increasing accessibility, portability, and interactivity of educational media affects science learning and interest is a new and important question. Informal learning research must not only address the ever-evolving pathways to scientific knowledge but also the complex ways in which media are used. A science comic may be read from cover-to-cover in one sitting or may be read sporadically over the course of a day, a week, or even longer. The comic may be read at school or at home, as part of an assignment or chosen from the library, and read on paper or an electronic device. In some cases, a teacher or even another student has created the comic. Understanding the different ways that people engage with media is crucial to developing a better understanding of informal learning.

CONCLUSIONS

A main goal of using comics in the classroom has been the improvement of literacy. By presenting a pictorial expression of verbal content, comics may help readers interpret words and sentences and notice important aspects of a story's setting, tone, and other contextual properties (e.g., Crawford, 2004; Frey & Fisher, 2004; Schwarz, 2007; Williams, 2008). Although literacy education is an important goal, our primary interest in this article involves learning of science. This educational goal may require comics that are specifically designed to communicate scientific topics to their readers—science comics.

The intent of science comics is twofold: to entertain and to educate. It can be difficult to strike a balance between these two goals. Science comic creators therefore face many difficult decisions about whether and how scientific information is displayed, whereas children, parents, and educators make judgments about whether a comic fits their criteria for reading. Some comics, such as the *World of Viruses* series, were created through collaboration between scientists and comic writers and artists. Although such comics may lead to unexpected and unintended consequences (as discussed earlier), we believe collaboration between scientists and comic creators is integral to creating comics that are scientifically accurate as well as entertaining (see also Tatalovic, 2009).

The main thrust of this article is that learning from science comics could be better understood and possibly improved by considering the cognitive impacts of the medium, in addition to more overarching factors including the conditions under which science comics are read and by whom. This article discussed several cognitive factors relevant to learning from science comics, and there are likely many additional factors besides the ones covered here. For further progress to be made, educational research is needed to empirically test the cognitive impact of comics. Thus, in addition to input from domain experts and talented writers and artists, the creation of effective science comics must draw on the science of learning and cognition. Through such research and collaboration, we stand to maximize the educational impact of this popular and potentially powerful medium.

NOTES

1. McCloud (1993) defined comics as "juxtaposed pictorial and other images in deliberate sequence, intended to convey information and/or to produce an aesthetic response in the viewer" (p. 20). Simple one-panel comic art, such as *Family Circus*, is excluded from this definition because it is nonsequential. Yet other staples of the funny pages, such as *Beetle Bailey*, as well as more epic works, such as Moore and Gibbons' *Watchmen*, would qualify as comics (comics such as Watchmen are often referred to as graphic novels—essentially a long comic, often bound in more durable format and found in bookstores rather than magazine stands).

2. There are other attempts to use comic books for science education that do not involve science comics in particular. For example, Feder (2002) describes how a physics lesson can be structured around

questions about familiar superheroes; for example, how fast does the Flash run? Along these lines, James Kakalios's (2006) book *The Physics of Superheroes* explains a number of physics phenomena, like thermodynamics and magnetism, through descriptions of popular superheroes. A different example comes from Mayo (2011) who describes how a classroom lesson on aphasia was enhanced by analyzing the character Grandpa Jim, a stroke victim, from the comic strip *For Better or For Worse*. Although such uses of popular comics for science education are not the focus of this article, these examples highlight some different ways that comics might enhance learning and instruction.

3. We thank an anonymous reviewer for raising the issue of stereotype effects.

REFERENCES

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences, 22*(4), 577–660.

Bartlett, F. C. (1932). *Remembering: A study in experimental and social psychology*. Cambridge, MA: Cambridge University Press.

Bell, P., Lewenstein, B., Shouse, A. W., & Feder, M. A. (Eds.). (2009). *Learning science in informal environments: people, places, and pursuits*. Washington, DC: National Academies Press.

Bitz, M. (2009). *Manga high: Literacy, identity, and coming of age in an urban high school*. Cambridge, MA: Harvard Education Press.

Bower, G. H., Black, J. B., & Turner, T. J. (1979). Scripts in memory for text. *Cognitive Psychology*, *11*, 177–220.

Carey, S. (1985). *Conceptual change in childhood*. Cambridge, MA: Bradford Books.

Casey, M. B., Nuttall, R., Pezaris, E., & Benbow, C. P. (1995). The influence of spatial ability on gender differences in mathematics college entrance test scores across diverse samples. *Developmental Psychology*, *31*, 697–705.

Crawford, P. (2004). Using graphic novels to attract reluctant readers and promote literacy. *Library Media Connection*, *22*(5), 26–28.

Dede, C. (2009). Immersive interfaces for engagement and learning. *Science, 323*(5910), 66–69.

Downs, R., & DeSouza, A. (Eds.). (2006). *Learning to think spatially: GIS as a support system in the K-12 curriculum*. Washington, DC: National Academies Press.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.). (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: National Academies Press.

Epley, N., Waytz, A., & Cacioppo, J. T. (2007). On seeing human: A three-factor theory of anthropomorphism. *Psychological Review*, *114*(4), 864–886.

Estes, D. (1998). Young children's awareness of their mental activity: The case of mental rotation. *Child Development*, *69*(5), 1345–1360.

Falk, J. H., & Dierking, L. D. (2010). The 95 percent solution: School is not where most Americans learn most of their science. *American Scientist*, *98*(6), 486–493.

Feder, T. (2002). Teaching physics with superheroes. *Physics Today*, *55*(11), 29–30.

Fies, B. (2006). *Mom's cancer*. Retrieved October 2, 2011, from http://www.momscancer.com/.

Frey, N., & Fisher, D. (2004). Using graphic novels, anime, and the Internet in an urban high school. *English Journal*, *93*(3), 19–25.

Gentner, D., & Markman, A. B. (1994). Structural alignment in comparison: No difference without similarity. *Psychological Science*, *5*(3), 152–158.

Ginns, P. (2006). Integrating information: A meta-analysis of the spatial contiguity and temporal contiguity effects. *Learning and Instruction*, *16*(6), 511–525.

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review*, *9*(3), 558–565.

Graesser, A. C., León, J. A., & Otero, J. C. (2002). Introduction to the psychology of science text comprehension. In J. Otero, J. A. León, & A. C. Graesser (Eds), *The psychology of science text comprehension* (pp. 1–15). Mahwah, NJ: Lawrence Erlbaum Associates.

Graesser, A. C., Singer, M., & Trabasso, T. (1994). Constructing inferences during narrative text comprehension. *Psychological Review*, *101*(3), 371–395.

Green, M. J., & Myers, K. R. (2010). Graphic medicine: Use of comics in medical education and patient care. *BMJ*, *340*.

Greenfield, P. M. (2009). Technology and informal education: What is taught, what is learned. *Science*, *323*(5910), 69–71.

Hatano, G., & Inagaki, K. (1997). Qualitative changes in intuitive biology. *European Journal of Psychology of Education*, *12*(2), 111–130.

Höffler, T. N., & Leutner, D. (2007). Instructional animation versus static pictures: A meta-analysis. *Learning and Instruction*, *17*(6), 722–738.

Hosler, J. (2000). *Clan apis*. Columbus, OH: Active Synapse.

Hosler, J. (2008). *Optical allusions*. Columbus, OH: 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.

Hughes-Hassell, S., & Rodge, P. (2007). The leisure reading habits of urban adolescents. *Journal of Adolescent and Adult Literacy*, *51*(1), 22–34.

Hutchinson, K. H. (1949). An experiment in the use of comics as instructional material. *The Journal of Educational Sociology*, *23*(4), 236–245.

Kakalios, J. (2006). *The physics of superheroes*. New York: Gotham Books.

Keogh, B., & Naylor, S. (1999). Concept cartoons, teaching and learning in science: An evaluation. *International Journal of Science Education*, *21*(4), 431–446.

Krajcik, J., McNeill, K. L., & Reiser, B. J. (2008). Learning-goals-driven design model: Developing curriculum materials that align with national standards and incorporate project-based pedagogy. *Science Education*, *92*(1), 1–32.

LeBlanc, S. (2011, February 11). Biff! Pow! MIT economist turns to comic book format to help explain Obama health care law. *Chicago Tribune*. Retrieved February 16, 2011, from http://www.chicagotribune.com/sns-ap-us-health-care-comics-books,0,787857.story.

Maki, R. H. (1998). Test predictions over text material. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Metacognition in educational theory and practice* (pp. 117–144). Hillsdale, NJ: Lawrence Erlbaum Associates.

Martin, B. E., & Brouwer, W. (1991). The sharing of personal science and the narrative element in science education. *Science Education*, *75*(6), 707–722.

Matuk, C. (2010). *Narratives in mind and media: A cognitive semiotic account of novices interpreting visual science media*. Unpublished doctoral dissertation, Northwestern University—Illinois.

Mayer, R. E. (2003). The promise of multimedia learning: Using the same instructional design methods across different media. *Learning and Instruction*, *13*(2), 125–139.

Mayer, R. E., Steinhoff, K., Bower, G., & Mars, R. (1995). A generative theory of textbook design: Using annotated illustrations to foster meaningful learning of science text. *Educational Technology Research and Development*, *43*(1), 31–44.

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.

McCloud, S. (1993). *Understanding comics: The invisible art*. Northampton, MA: Kitchen Sink Press.

McNamara, D. S., Kintsch, E., Songer, N., & Kintsch, W. (1996). Are good texts always better? Interactions of text coherence, background knowledge, and levels of understanding in learning from text. *Cognition and Instruction*, *14*(1), 1–43.

The Medikidz Story. (n.d.). Retrieved October 2, 2011, from http://www.medikidz.com/medikidz-story/.

Millard, E., & Marsh, J. (2001). Sending Minnie the Minx home: Comics and reading choices. *Cambridge Journal of Education*, *31*(1), 25–38.

Moreno, R., & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology*, *91*(2), 358–368.

Naylor, S., & Keogh, B. (1999). Constructivism in the classroom: Theory into practice. *Journal of Science Teacher Education*, *10*(2), 93–106.

Olson, J. C. (2008). *The comic strip as a medium for promoting science literacy*. Retrieved November 1, 2011, from http://www.csun.edu/~jco69120/coursework/697/projects/Olson ActionResearchFinal.pdf

Ottaviani, J. (2003). *Dignifying science: Stories about women scientists*. Ann Arbor, MI: G.T. Labs.

Özdemir, E. (2010). *The effect of instructional comics on sixth grade students' achievement in heat transfer*. Unpublished doctoral dissertation, Middle East Technical University—Turkey.

Park, J. S., Kim, D. H., & Chung, M. S. (2011). Anatomy comic strips. *Anatomical Sciences Education*, *4*(5), 275–279.

Powell, M., Floyd, T., Rubinstein, J., & Beachler, S. (2009). *The curse of the tree-man*. World of Viruses, University of Nebraska.

Rota, G., & Izquierdo, J. (2003). "Comics" as a tool for teaching biotechnology in primary schools. *Electronic Journal of Biotechnology*, 6(2). Retrieved November 1, 2011, from http://www.ejbiotechnology.info/content/vol6/issue2/issues/2

Schank, R. C., & Abelson, R. (1977). *Scripts, plans, goals, and understanding: An inquiry into human knowledge structure*. Hillsdale, NJ: Lawrence Earlbaum Associates.

Schwarz, G. (2007). Media literacy, graphic novels and social issues. *SIMILE: Studies In Media & Information Literacy Education*, *7*(4), 1–11.

Spiegelman, A. (1986). *Maus. A survival's tale: Volume 1. My father bleeds history*. New York: Pantheon Books.

Stein, N. L., Hernandez, M. W., & Anggoro, F. K. (2010). A theory of coherence and complex learning in the physical sciences: What works (and what doesn't). In N. L. Stein & S. Raudenbush (Eds.), *Developmental cognitive science goes to school* (pp. 87–112). New York: Routledge.

Sweller, J. (1994). Cognitive load theory, learning difficulty and instructional design. *Learning and Instruction*, *4*(4), 295–312.

Symons, C. S., & Johnson, B. T. (1997). The self-reference effect in memory: A meta-analysis. *Psychological Bulletin*, *121*(3), 371–394.

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

Thiede, K. W., Griffin, T. D., Wiley, J., & Anderson, M. (2010). Poor metacomprehension accuracy as a result of inappropriate cue use. *Discourse Processes*, *47*(4), 331–362.

Tversky, B., Bauer-Morrison, J., & Bétrancourt, M. (2002). Animation: Can it facilitate? *International Journal of Human-Computer Studies*, *57*(4), 247–262.

Tversky, B., Heiser, J., Mackenzie, R., Lozano, S., & Morrison, J. (2008). Enriching animations. In R. Lowe & W. Schnotz (Eds.), *Learning with animation: Research implications for design* (pp. 263–285). New York: Cambridge University Press.

Van Dijk, T. A., & Kintsch, W. (1983). *Strategies of discourse comprehension*. New York: Academic.

Vosniadou, S., & Brewer, W. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, *24*(4), 535–586.

Weitkamp, E., & Burnet, F. (2007). The Chemedian brings laughter to the chemistry classroom. *International Journal of Science Education*, *29*(15), 1911–1929.

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

Correspondence regarding this article should be directed to Benjamin D. Jee, Department of Psychology, College of the Holy Cross, 1 College Street, Worcester, MA 01610. E-mail: bjee@holycross.edu