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How Do Teachers Use Comics to Promote Engagement, Equity, and Diversity in Science Classrooms?

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Abstract

Equitable learning opportunities are critical to the goals of science education. However, major curriculum standards are vague on how to achieve equity goals, and educators must often develop their own resources and strategies to achieve equity goals. This study examines how educators used a comic book series designed to interest youth in virology as a way to make science more broadly appealing to their diverse students. We begin with the notion of Pedagogical Design Capacity, which describes a dynamic relationship between teachers and their tools and the ability for teachers to perceive and leverage affordances of artifacts as tools in their curriculum design. In a qualitative analysis of 18 interviews with educators, survey responses, instructional artifacts, and classroom observations, we describe the potential that educators saw in the comics and the strategies they used to take advantage of that potential to promote equitable science teaching. Notably, we observed how the comics enabled educators to incorporate multiple literacies and disciplinary lenses into their lessons, thereby expanding traditional views of science literacy. We documented the range of techniques by which they used comics and fictional narratives to support specific scientific practices, such as modeling. We also observed

challenges that participants encountered in using comics, which included overcoming their own and their students' attitudes and beliefs regarding the role of informal reading materials in science education.

By investigating how resourceful science educators use comic books, this study informs both researchers and educators on how innovative curriculum materials can broaden and diversify participation in science. Findings have implications for the design of similar curriculum materials and instructional approaches, as well as professional development to support equitable science teaching.

Keywords: Equity, Classrooms, Comic books, Instructional strategies, Science education, Teachers

Introduction

A major goal in science education is to increase participation by learners from under-represented populations. One way to do this is to create entry points for those who may otherwise not identify with the discipline. Such entry points can be created by building on learners' diverse needs, interests, and motivations as resources in learning. In integrating science and engineering, the Next Generation Science Standards (NGSS, NGSS Lead States 2013) have taken steps toward relating science to real-world applications and to issues that are relevant to learners.

Making science relevant is only a small step toward engaging diverse learners. Rodriguez (2015) argues that "*a new dimension of engagement, equity and diversity* should have been added to the conceptual framework [of the NGSS] and the new standards to make a stronger case in support of closing the achievement gap." (p. 1041, his emphasis). Without attention to equity, engagement, and diversity, Rodriguez predicted that the new guidelines will have as little impact as previous standards on the teaching of science. If standards are to truly aid in broadening participation in STEM, then equity, engagement, and diversity issues must be as central in focus as disciplinary issues and not merely mentioned in an appendix (NGSS Lead States 2013). In practice, teachers have few explicit guidelines for creating engaging and equitable science learning environments for their diverse students.

This paper explores how science comics, by their connection to students' personal interests and their integration of multiple disciplinary perspectives on science topics, can encourage broader and more equitable participation in STEM. Beginning with the view of comic books as tools that both shape and are shaped by teachers' beliefs and practices, we studied why teachers adopted comic books and how they used them to address equity and diversity issues in their classrooms. By describing teachers' strategies and approaches for using comic books, this research contributes to both theory and practice. More specifically, it expands our theoretical understanding of the roles of

popular media in supporting both disciplinary and motivational goals of instruction, and it documents strategies and approaches to inform efforts to create equitable science learning environments in classrooms.

We first situate this study within an expanded definition of scientific literacy and its relation to equity in education. We next explore the notion of comic books as teaching tools for promoting science learning, literacy, and equity. Then, we present a study that examines—through analyses of interviews, surveys, classroom observations, and teachers' instructional artifacts—the potential that teachers perceived in comics and how they sought to realize that potential through the integration of comic books into their instruction.

Background

Equity as a Goal for Science Education

Success in STEM is determined by, among other things, students' socioeconomic status, access to resources and social capital, language background, gender, racial/ethnic group, and disability status. Eliminating achievement gaps by offering all students, regardless of their backgrounds, the same opportunities to learn and participate in science is thus a critical goal for science education (National Research Council 2012) and for other educational initiatives (The White House 2014). It is also a goal that is particularly relevant given the increasing diversity of cultures, abilities, languages, and socioeconomic statuses within classrooms (e.g., Asowayan et al. 2017).

The concepts of equity, diversity, and engagement are highly interrelated and thus often used in conjunction. Diversity in education refers to the multitude of perspectives found juxtaposed in learning environments due to globalization and to more inclusive educational settings. Students in classrooms represent a variety of cultures, ethnicities, languages, worldviews, economic backgrounds, and abilities. Such diversity can benefit learning by enriching students' perspectives, and allowing them to practice ways to interact productively with peers of different backgrounds. However, diversity also presents challenges. Teachers who are ill-prepared to engage with diversity not only fail to take advantage of what it has to offer, but can also contribute to climates of discrimination and social injustice (Banks 2015).

Diversity is thus tightly wound with issues of equity in education. Equity refers to all learners, regardless of their differences, having the same access to opportunities to succeed. Inequities arise when certain groups are privileged to succeed over others due to disparities in social standing and resource access (Unterhalter 2009).

Engagement is likewise related to equity and diversity. Engagement in education refers to learners' identification and participation in disciplinary

practices (Finn 1989). Learners' engagement is determined by behavioral (e.g., persistence, rule following), cognitive (e.g., strategy use, psychological commitment), and emotional (e.g., interest, values) aspects. These are in turn influenced by learners' backgrounds and access to relevant resources (e.g., role models, community values, access to extracurricular enrichment experiences). Diverse students may thus engage in different domain areas for different reasons. When teachers are prepared to acknowledge and address students' diverse needs, they can find ways to provide more equitable opportunities for all their students to engage (Nieto 2000).

Culturally relevant pedagogy (e.g., Ladson-Billings 2014) and culturally responsive teaching (Gay 2013), though founded in an interest in improving the educational experiences of traditionally underserved student populations, particularly students of color (Ladson-Billings 1995a), also describes strategies that are "just good teaching," and that benefit all students (Ladson-Billings 1995b). In line with this thinking, the NGSS Diversity and Equity Team added the topic of equity, engagement, and diversity to Appendix D of the NGSS (NGSS Lead States 2013) along with some strategies for making science accessible to all students. This appendix synthesizes the work of other scholars who argue that equity can be achieved by recognizing and building upon students' existing funds of knowledge, personal interests, and identities; legitimizing various ways of expressing ideas; making links to students' linguistic or cultural backgrounds; providing adequate resources to support all students' learning in science; and creating connections between the informal youth discourses and formal scientific discourses (Banks et al. 2007; Bell et al. 2012; Gay 2013; Januszyk et al. 2015; Januszyk et al. 2016; Lee, Miller & Januszyk, 2014; National Research Council 2009; Ladson-Billings 2014).

In critiquing the decision to relegate issues of engagement, equity, and diversity to an appendix of the NGSS, Rodriguez (2015) offers guidelines for how educators might enact NGSS curriculum with specific regard to those issues. To promote engagement, educators might ensure that their content and pedagogical strategies are culturally relevant, and that they leave room for individual choice and expression. To promote equity, educators might ensure that accommodations are made for all students, no matter their abilities and resource access, to have to the same opportunities to learn and to demonstrate their learning. To promote diversity, educators should be inclusive of different viewpoints and experiences.

In this paper, we are primarily concerned with how teachers use comics to provide all students with opportunities to succeed in STEM. Because equity, diversity, and engagement are tightly interrelated, we will often use equity as an umbrella term, intended to also refer to issues of diversity and engagement. However, we will use the terms diversity and engagement when these issues are clearly most relevant and when we feel that readers will benefit from their distinction.

Fictional Texts as Tools for Inquiry and Equity

Text can play an important role in equitable science education. Indeed, students' academic achievement and ability to participate as citizens depend in part on their ability to read and write in subject areas including science (Jacobs 2008). Developing scientific literacy requires learners to not only master content knowledge but also recognize the diverse communicative and representational practices in professional science, which include generating, critiquing, and communicating with multiple representations (Duke et al. 2011; Duschl 2008; Kress et al. 2001). These representations may be formal texts, such as field notes, grant proposals, scholarly articles, and peer reviews, that serve to share, review, and build upon others' ideas; as well as informal texts, such as narrative and hybrid media, that serve to disseminate research findings to general audiences, and to educate scientifically literate citizens and future STEM workers (Goldman and Bisanz 2002).

There is now general recognition of the value of supporting students to develop multiple literacies. Indeed, curriculum reforms around the world encourage greater integration of science with language arts. For example, the Common Core State Standards (CCSS) of the USA emphasize the development of students' abilities to describe and analyze information presented in multiple formats and media (National Governors Association Center for Best Practices and Council of Chief State School Officers 2010). Seeds of Science/Roots of Reading is one CCSS-aligned elementary curriculum found to improve students' performance in science, writing, and vocabulary, including the performance of English Language Learners (Goldschmidt and Jung 2011). Likewise, Norway's Budding Scientist and Literacy curriculum (Ministry of Education and Research 2006) places importance on advancing science inquiry through reading and writing. A study of literacy practices in Norwegian primary level science classrooms that employed this curriculum found students engaged with texts and literacy practices that extended beyond their school context to their everyday experiences (Sørvik et al. 2015). Relatedly, students who experienced inquiry-based science lessons, that infused the reading of science trade books and explicit teaching of reading strategies, were found to outperform their peers, who experienced an inquiry-only approach (Fang and Wei 2010). Other classroom-based studies in the USA confirm and extend these findings to students across socio-economic statuses, races, and ethnicities (Tong et al. 2014) as well as gender (Guzzetti and Bang 2010).

Fictional texts, while not typically considered in the same category as science texts, offer alternative ways of understanding science that can align with equity goals. When used for inquiry, such texts can offer both contexts and tools for developing students' hands-on science inquiry, and vice versa. In fact, engaging in text-based inquiry shares similar practices with hands-on

inquiry, such as asking questions, drawing inferences, and constructing evidence-based arguments (Goldman and Bisanz 2002; Hand et al. 2003; Pearson et al. 2010; Yore et al. 2004). At the same time, fictional texts introduce stories, characters, and contexts, which can allow readers to connect science to personal experiences and to empathize with others' viewpoints. Some research indicates that educators using science fiction films can make better connections across the curriculum, more effectively address students' scientific misunderstandings, increase students' interest in and critical thinking about the world, and heighten their desire to follow science-related careers (e.g., Dark 2005; Harwood and McMahon 1997; Laprise and Winrich 2010; Lin 2014). Such findings point to the promise of using multiple kinds of texts for supporting students in developing both literacy and science practices (Cervetti et al., 2009). At the same time, researchers caution against using, such findings as prescriptive, without also understanding teachers' roles in integrating these media into their instruction (Oppenheimer 2003).

Challenges with Integrated Science and Literacy Instruction

There are several challenges for educators to integrate literacy and science. First, is a lack of professional development: Teachers tend not to be formally prepared to effectively incorporate literacy into their science instruction (Lee 2004). Instead, informational textbooks can tend to dominate among the materials teachers use, and these greatly influence teachers' instruction (Nelson 2006; Yore 1991; Yore et al. 2003). Textbooks tend to be opaque, challenging, and unrelatable to struggling science readers (Lee and Sprattley 2010). Moreover, because teachers mainly use science textbooks as references from which students copy and organize information into their personal notes (Driscoll et al. 1994; Lyons 2006; Osborne and Collins 2001), it can be rare for students to engage in other literacy practices around science texts, such as generating text and engaging in metatextual reasoning about an author's purpose and intended audience (Af Geijerstam 2006; Danielsson 2010). This narrow view of what texts can constitute science texts and limited strategies for using them, may contribute to the perception that doing science is about memorizing a static body of knowledge (Lyons 2006).

A second challenge is the limited availability and access to texts that meet the needs of students with different reading abilities (Schlepppegrell 2004), as well as curriculum materials and strategies to guide teachers in integrating texts in ways that meaningfully support science learning (Goldman and Bisanz 2002). A third challenge is that wider-scale efforts to integrate literacy into science instruction have been overwhelmed by a focus on hands-on inquiry approaches (Pearson et al. 2010; Wellington and Osborne 2001). Whereas inquiry approaches to science can result in equitable opportunities for students of color (Geier et al. 2008; Wilson et al. 2010),

neglecting the roles of multiple kinds of texts also neglects opportunities to cultivate the many other practices that are critical for diverse students' STEM success.

By addressing the lack of research on how teachers currently use various existing texts to support science learning (Cervetti et al., 2009; Pappas 2006), we hope to expand the view of what counts as a science text and to learn from what educators are already doing in order to inform others' efforts to promote equitable opportunities for science learning in their classrooms. This study focuses specifically on how teachers sought to exploit comic books as tools for equitable science instruction.

Comics in Science Education

Comic books—or simply, *comics*—refer to a literary form that consists of a deliberate sequence of images, often juxtaposed with text in the form of speech bubbles and text boxes (McCloud 1993; Tatalovic 2009; Ogier and Ghosh 2017). Comics have long been popular in youth culture, and to date, libraries report high interest in comics as reading materials among youth (Gavigan 2014).

Educational comics, which are designed to be both entertaining and educational (Alaba 2007), can engage learners in complex literacy practices that cross formal and informal experiences. They integrate visual and textual modes of communication; they feature literary devices, such as metaphor, alliteration, colloquialism, dialog, plot, theme, symbolism, personification; and they embed topics, such as science, history, and social issues within narrative accounts. However, comics have also been historically controversial and under-researched in their role as educational materials. For decades, educators regarded comics with derision, believing them to be neither robust, serious, nor challenging enough to merit classroom time (Hutchinson 1949; Millard and Marsh 2001). In spite of their historical reputation, educational comics have proliferated over the past two decades and exhibit a range of uses of visual imagery, narrative, and subject matter. Among notable examples, *Clan Apis* (Hosler 2000) describes bee behavior through a story of anthropomorphized bees; *Feynman* (Ottaviani and Myrick 2011) and *Dignifying Science* (Ottaviani 2003) are graphical autobiographies of famous scientists; and *Optical Allusions* (Hosler 2008) offers a nonfiction comic alternative to a traditional physics textbook. Moreover, the growing series *Science Comics*, published by First Second Comics, an imprint of Macmillan, thus far covers topics such as flight (Wilgus and Brooks 2017), volcanoes (Chad 2016), plagues (Koch 2017), and dinosaurs (Reed and Flood 2016).

Claims about educational comics have attributed their value to many things. For example, comics can expand students' comprehension by exposing them to multiple forms of text (Jennings et al. 2014). They are objects of

interest in that they can evoke esthetic responses from readers through their visual and narrative design. Accordingly, educators report finding comics to be effective hooks and accessible introductions to more academic topics (e.g., Jacobs 2007; Lapp et al. 2011; Norton 2003). Comics also have many features that make them suitable for learning complex topics (Jee and Anggoro 2012): They concretize abstract science concepts through visualization and support understanding through the integration of words and pictures. They also help to organize complex information within a narrative structure, and invite readers to relate emotionally to characters and situations through personification of inanimate things.

Creating comics furthermore has several benefits for learning. As multi-modal texts, they require creators to coordinate different media and genres. This can create opportunities for students to make connections between what they have learned in school, at home, and in their larger community (Gonzalez et al. 2005). When comics are used to critique and to make scientific arguments, they may show many of the other benefits of student-generated representations (e.g., Acher et al. 2007; Schwarz and White 2005; Stratford et al. 1998; Wilensky and Reisman 2006; Windschitl et al. 2008). For example, student-generated representation function as means for eliciting and assessing students' understanding and revealing their representational competence (Hall et al. 1997). They moreover prompt students to reflect on their current ideas and to engage in more self-monitoring behaviors (Van Meter 2001). Compared to reading expository texts, generating representations helps students to deepen and build on their understanding (Van Meter et al. 2006). They do so by helping to develop students' mental representations (Lansing 1981, 1984), enable inferences (Bobek and Tversky, 2016), and promote conceptual change (Edens and Potter 2003). Finally, generating representations also engages students in practices that are central to scientific inquiry, including modeling, evaluating, and revising theories (Acher et al. 2007; Frankel 2005; Pillsbury 2008; Wu and Krajcik 2006; Schwarz and White 2005; Stratford et al. 1998; Wilensky and Reisman 2006; Windschitl et al. 2008). Students and teachers can come to better engage with and understand science ideas, as well as appreciate how scientists' construct and communicate knowledge.

The pace at which educational comics have proliferated in classrooms and other educational contexts far exceeds the empirical research being done on their effectiveness (Jee and Anggoro 2012). A handful of studies indicates the potential of comics to support conceptual science learning (e.g., Aleixo and Sumner 2017; Hosler and Boomer 2011; Olson 2008; Özdemir 2010; Rota and Izquierdo 2003; Weitkamp and Burnet 2007); to incite interest in, enjoyment of, and positive attitudes toward science (e.g., Hosler and Boomer 2011; Özdemir 2010); and to promote self-identification as scientists, particularly among students with initially low science identity (Spiegel et al. 2013).

This evidence points to the promise of comic books for promoting equitable science learning opportunities. By understanding the opportunities for equity that teachers perceive in comics, how teachers are already leveraging those opportunities in their instruction, and what challenges they face in doing so, we can inform our view of the role of comic books as tools for teaching, and also develop better supports for the use of comics in promoting equitable science instruction.

Theoretical Framework

Comic Books and Pedagogical Design Capacity

We view teaching as a design practice: a continuous curriculum refinement that occurs through cycles of planning, enactment, and reflection. Key to teaching is the relationship between teachers and the curriculum artifacts that constitute their design materials. These artifacts, which may include supplementary and central texts, references, models, and visualizations, serve as tools at each stage of teachers' design process (Brown 2009). How these tools are used engages a dynamic interplay between teachers' goals, skills, knowledge, and beliefs regarding pedagogy and subject matter, as well as the specific design affordances of the tools. More specifically, in deciding what artifacts to select, how to fit them within their larger curricular goals, how to build activities upon them, and how to align these activities with the affordances of the artifacts and their learning goals for their students, teachers must have mastery over the subject area and its associated pedagogical strategies.

The manners by which teachers enact curriculum are determined by teachers' Pedagogical Design Capacity (PDC) (Brown 2009): their ability to perceive and leverage the affordances of artifacts in their curriculum design. An individual teacher's PDC involves, to varying degrees, their use of curriculum resources (e.g., tools, procedures, representations), and personal resources (e.g., beliefs or motivations underlying their choices, knowledge of the content, and knowledge of relevant pedagogical approaches). Some teachers may rely more or less on either the curriculum resources or on their personal resources, which determine the manners by which teachers enact curriculum materials. For example, a teacher who relies mainly on a curriculum's resources may offload much of their instructional decisions onto those resources. To support such approaches, *educative curriculum materials* are developed, which intentionally embed guidance for teachers on how to best incorporate those materials into their instruction (Arias et al. 2016; Davis et al. 2017). Meanwhile, a teacher who relies mainly on his or her personal resources may adapt or improvise upon the given curriculum materials

based on their individual beliefs, motivations, and knowledge of the subject matter and relevant pedagogical approaches.

In either case, understanding the teacher-tool relationship requires acknowledging how the features of a given curriculum artifact, as well as how teachers' own resources, enable, and limit what is possible for teaching and learning. Educative curriculum materials can support instructional decisions by developing teachers' knowledge of the subject matter, promoting awareness of relevant pedagogical approaches, suggesting ways to relate materials to other learning activities, and helping them to anticipate and respond to students' ideas (Davis and Krajcik 2005). In contrast, popular culture artifacts do not embed such guidance. As they are not necessarily designed to address specific curriculum goals, they can leave teachers to rely on their own personal resources to recognize the materials' potential for adoption, to imagine strategies for incorporating them, and to enact them in ways that are aligned with their views and responsive to their students' needs. In this sense, using popular culture materials as curriculum artifacts can present challenges to teachers with regard to how to use them. For these same reasons, observing teachers' uses of popular culture materials also presents an opportunity to better understand teachers' values and priorities for science instruction and their views regarding the role of informal learning materials within formal science education. Research on how curriculum artifacts are adopted, incorporated, and enacted should thus acknowledge both teachers' practices, and the contribution of the design of those artifacts.

Comic books present a degree of risk to teachers who choose to adopt them as curriculum artifacts: School administrators may not support their use in the classroom; teachers may not have adequate examples, guidelines, or classroom time to develop meaningful lessons based on them if they are unfamiliar texts; and teachers may also lack the financial resources necessary to purchase high quality publications. Moreover, teachers may face external constraints imposed by local testing requirements and curriculum standards, as well as personal ones related to the alignment of strategies with personal dispositions (e.g., beliefs, attitudes, values, and competencies with regard to teaching, learning, and innovation in science education).

As with other curriculum materials, comics might address these issues by being free or low-cost, easy to find, accompanied by guidance for use (e.g., sample lesson plans, professional development opportunities), and explicit in their alignment to relevant standards. As described above, however, science comics also introduce multiple disciplinary lenses outside of science and engage multiple kinds of literacies, which can challenge teachers' beliefs and values as science educators, as well as their views on what constitutes science education. Thus, understanding the role of the design of such curriculum materials in teachers' instructional choices becomes important for supporting teachers' practices.

Few studies have directly examined the contribution of the design of curriculum artifacts to teachers' uses of those artifacts in their curriculum decisions. For example, Sherin and Drake (2009) examined mathematics curriculum strategies in terms of how teachers engaged in reading, evaluating, and adapting curriculum materials prior to, during, and after instruction. While this work is important for understanding teachers' own practices and how to support them, it does not necessarily address the specific role of the design of the curriculum materials in shaping teachers' practices. Likewise, Sørvik et al. (2015) examined the literacy practices apparent in classrooms that integrate reading and science instruction. Their analysis focused on students' views and experiences with broad categories of texts (e.g., fictional, informational, internet-based). Again, such work is critical for understanding learners' experiences with multiple textual forms. However, it does not query specific design features of those texts and so does not necessarily add to our understanding of the role of design in those experiences. More importantly, existing related work tends to focus on the value of curriculum artifacts for promoting disciplinary learning, rather than classroom equity.

Comic Books as Tools for Classroom Engagement, Equity, and Diversity

Through our exploration of teachers' adoption and integration of the *World of Viruses* comics (WoV, Diamond et al. 2012), we examine comic books as curriculum artifacts for promoting teachers' goals with regard to classroom engagement, equity, and diversity. WoV consist of five comic books created by a larger project to promote the public understanding of virology (Diamond et al. 2015, Fig. 1). Designed to support youth's informal science learning by being both informative and engaging to adolescent readers, each comic presents a story focused on a specific virus and is accompanied by a two-page essay presenting the same information but in a different format (Table 1). The five comics and their essays are published together in paperback format and have been freely distributed to teachers at conferences and professional development opportunities. They are also free to download or read online (worldofviruses.unl.edu/comics-apps, Diamond et al. 2012; Spiegel et al. 2013), and print copies are available for purchase (e.g., Amazon.com).

The right-most column indicates the number of participants who included each resource in their lessons. Some participants assigned and required only one comic, while others made multiple comics available from which students could choose. In addition to these counts, four teachers did not integrate the comics into their lessons, but instead made all the comics available for their students to read during their free time.

In understanding comic books as curriculum artifacts, it becomes important to know how comic books can promote teachers' PDC. That is, what about the comics makes teachers willing to adopt them in their instruction

Table 1. Descriptions of The World of Viruses comic stories (Diamond et al. 2012) and essay collection (Zimmer 2015)

Comic title	Description	# participants who included it in their lessons
Confined!	Foot-mouth-and-hand disease virus (FMDV): Following different strains of FMD kept in the Plum Island Animal Disease Center, this comic explores labs like Plum Island in their effort to create vaccines for FMD, the history of different FMD strains, and why it's so difficult to eradicate all strains of FMD.	11
Phantom planet	HIV: Set in a dystopian future where HIV has overtaken humanity, the narrative follows two scientists who grew up in human outer space colonies as they take samples of HIV resistant cells in an effort to save humanity. The comic teaches not only about HIV but also how HIV resistance works.	10
The never-ending battle	Ocean viruses (EhV): This comic focuses on how an ocean virus such as the <i>Emiliana huxleyi</i> virus controls algal blooms in the ocean, ensuring that algae growth will not run rampant and maintain a healthy amount of oxygen in the Earth's atmosphere for life to continue.	12
The frozen horror	Influenza virus: Set in "The Land of Haunted Shadows," where 103 native villagers were killed by influenza over the span of 6 days; this comic follows a pathologist sent to investigate this 1918 outbreak and tells how a strain of influenza virus spread from a girl to the rest of the village, leaving only four survivors.	12
Curse of the Tree man	Human papillomavirus (HPV): Following the point of view of HPV, the reader learns how the virus infects and spreads in the body despite the body's innate immune system. The story continues from the point of view of the infected individual, whose unique genetics have allowed the HPV to grow out of control over many years and have led him to earning his living in a traveling circus as a "Tree Man."	10
Planet of viruses	A collection of essays by the journalist, Carl Zimmer, on which the comic stories were based.	3

- (2) *Authenticity to the science.* Being authentic to the science means addressing topics in ways that do not pander to young readers. For example, WoV comics do not shy away from addressing conceptually complex ideas, from biological processes to environmental impacts to ethical and moral dilemmas. The comics also contain realistic visual representations of diseases, rather than mask such information with euphemisms.
- (3) *Leverageable content.* WoV comics touch on many topics; topics related not only to virology but also to historical events, ethical issues, and futurism. Such strategic subject integration offers teachers the ability to connect the content to bigger disciplinary ideas aligned with their instructional goals. By offering multiple disciplinary lenses through which to examine a topic, readers may build a systems-level view and deeper understanding of it.

(4) *Relatability*. Materials that relate to the form and content of youth cultural artifacts can ensure that youth choose and engage with them. Science comics can ensure relatability through their format and through their stories. For example, WoV comics were codeveloped, written, and illustrated through a partnership between professional comic creators, science writers, and virologists in order to achieve an esthetic and production quality that meets youths' expectations (Spiegel et al. 2013). Through stories that involve relatable characters that reflect youths' own racial, ethnic, and cultural identities, WoV comics can moreover encourage youth to imagine themselves taking on roles in STEM, which may be a step toward their longer term disciplinary engagement.

The above features of science comics can work in synergy to appeal to youth with diverse interests and to promote more equitable science learning. For example, a comic book's authenticity as a youth cultural artifact can encourage interest and deep engagement among those who are traditionally disengaged from STEM. The comic's fantastical elements can offer analogies for understanding complicated science ideas (Matuk et al. 2009), and futuristic narratives about the human and environmental impacts of viruses can encourage readers to engage in such scientific practices as hypothesizing and predicting. However, teachers must be able to recognize these potential leverage points in order to fully exploit their value.

Research Questions

By exploring the approaches of teachers who have taken the risk of incorporating comic books into their science teaching, we seek to understand the potential of comic books as curriculum artifacts and their affordances for supporting teachers' attempts to create equitable science learning opportunities for their students. Specifically, we ask:

1. What potential do teachers see in comics for promoting equitable science learning? That is, what features of comics do teachers recognize as being useful for supporting their efforts to create equitable science learning opportunities for their students?
2. How do comic books support teachers' equitable approaches to science teaching? In other words, how do teachers build upon the features of comic books, and enact their potential through the activities they conduct in their classrooms?
3. What challenges do teachers encounter in using comic books in their teaching? This final question would illuminate the benefits of comics in relation to their potential difficulties, and is important for informing other teachers' decisions about using comics in their own teaching.

Methods

Participants

Participants were 18 educators (17 teachers and 1 school health technician) from a mid-sized urban city in the north central USA. The educators came from 11 different public schools, two of which were Title 1 schools (Table 2). They encountered our materials during our project outreach efforts at a district-wide professional development workshop. Some of these educators were new to the project, while others had collaborated with the WoV principal investigator (author 4) in various other projects over the past 20 years.

Viruses and bacteria have traditionally been included in the seventh grade curriculum in this school district, and biology is usually first taken during 10th grade. Project materials designed to support the teaching of microbes included the WoV comic, the book *Planet of Viruses* (Zimmer 2015), a microbe sticker book, and online resources (e.g., scientifically accurate illustrations of viruses; expert-rated lesson plans). Thirty-seven local area educators requested and received classroom sets of the WoV comic, as well as some of the other print materials. Later, we followed up with these individuals by email to understand how they used the project materials and 18 of them consented to be interviewed and to also complete a brief survey (Appendix B).

Data

Our data consist of surveys and interviews with 18 educators, observations of five teachers' classrooms, and analyses of teaching artifacts from six teachers.

Individual, semi-structured interviews lasted 20–40 min. Some educators had previously used the comics either earlier during that year or during the prior year, and others were planning to use the comics later the academic year. Thus, the interview focused, when relevant to individual teachers, on

Table 2. Summary of participant educator demographics

Level	12 middle level ($n = 8$ at 7th grade) 5 high school biology
Gender	15 female 2 male
Race/ethnicity	16 White/Caucasian 1 Black/African American
Years of experience	2–25 years (average = 13 years)

the utility, strengths, and limitations they perceived in the comics, why they chose to adopt the comics, and the reasons for their approaches to incorporating them into their teaching (Appendix B).

At the end of their interviews, each educator completed a one-page survey on their demographics (Appendix A), how frequently they read comics and used them as teaching materials with their students, their attitudes toward using new educational materials, and the barriers they perceived.

Upon consent and within several months following their interviews, the third author observed teachers' classroom use of the WoV materials. These observations happened over 1–2 class periods for each teacher, depending on the amount of time and number of class periods that the teachers spent using the comic. Any differences between what participants expressed in their interviews and what we ultimately observed in our classroom observations were minor and not relevant to the purposes of this study. Instead, we focused on understanding the potential perceived by educators in the comics and their strategies for implementing them. We conducted observations in five classrooms. Classrooms of the other 13 educators were not observed because seven were either not planning on using the materials in class, were no longer teaching biology, or indicated to us that there would be little to observe (e.g., students would be doing independent reading and writing, or the materials would simply be available on the shelf for use during students' free time). The other six teachers had already used the materials earlier that school year and were not planning to use them again; or the timing of the class in which they were planning to use the comics did not allow us the chance to schedule an observation.

During the observations, the third author documented descriptive field notes about how the comic was used, as well as student-teacher interactions and discussion, assignments, and any supplementary materials that accompanied the lessons. In cases when time permitted following each class observation, students participated in a brief whole-class discussion with the researcher about the comics and responded to a one-page survey about the comics. A total of 176 students answered this survey, including 100 seventh graders, 37 eighth graders, and 39 high school students enrolled in a 10th grade biology class (87 male, 82 female, 4 other, 3 not reported).

Analysis

All interview recordings were transcribed and imported into INVIVO. A research assistant prepared the transcripts for analysis by applying descriptive codes (Miles, Huberman & Saldaña, 2014). These codes segmented the data by general topic, which included teachers' reasons for using comics, descriptions of their classroom activities, their expressed views on the value of the comics, and so forth. The descriptive codes allowed the first two

authors to then sort through the interview transcripts, field notes, survey responses, and artifacts, and to generate from these a matrix (Miles, Huberman & Saldaña, 2014). This matrix organized participants as cases and compared and contrasted their views and approaches to using the comics.

Interviews were semi-structured to allow teachers to highlight themes that they felt were personally compelling. This means that themes raised by some participants may have also been important to others, but simply not voiced. We therefore viewed participants' spontaneous mentions of themes as an indication of their salience. Because we cannot assume that a given theme was only important to those participants who happened to mention it in their interviews, we used the presence of a theme anywhere across our data and its relevance to our research questions, as criteria for noting it, rather than attempt to make claims about the frequencies at which these themes occurred.

We took a constant comparison approach to identify broad, initial themes (Glaser & Strauss, 1967) and to refine the matrix with evidence from across data sources. Our goal in doing so was to define a set of dimensions that we felt adequately described and explained teachers' reasons for and approaches to using the comics. This stage of analysis made salient to us the alignments of teachers' decisions with broader goals in education for promoting equity, diversity, and engagement, particularly as these were articulated by Rodriguez (2015). Accordingly, we organized our data under these goals to obtain a sense of the relationships between teachers' decisions and the perceived affordances of the comics.

Our findings report the affordances participants perceived in comics for addressing issues of equity, diversity and engagement; their approaches to enacting that potential, and the challenges they encountered in doing so. Most of the evidence reported below comes from our interviews with participants and our observations of their classrooms and teaching artifacts, when it was possible to document these. We also include responses from one participant, Erica, who was not a classroom teacher but rather a school health technician. Her responses offer valuable insights into the possibilities of comics to be incorporated for education outside of the classroom. When applicable, we draw on information from teachers' and students' survey responses to enrich this evidence. Sources of these data are specified as appropriate.

Findings

Below, we describe the potential teachers saw in comics for promoting equity in science learning, their approaches to enacting that potential, and the challenges they encountered.

What Potential Do Educators See in Comics for Promoting Equitable Science Learning?

Our first research question addresses teachers' PDC, which, as described above, refers to their ability to perceive and use the particular value in a curriculum artifact to meet their instructional goals. To answer this question, we asked our participants what they felt to be the strengths of the comics for their teaching purposes. Several responses pointed to the fact that the comics were different from their typical curriculum materials, which suggests that the novelty of the format compared to materials traditionally used was itself an advantage. Charlotte captured this sentiment when she noted, "I think they [the students] like that kind of stuff too because it doesn't seem like it's so textbook-y to them."

Other teachers commented on how the comics embedded science topics within engaging stories, how they were a medium that aligned with their students' existing interests, and how they made information concise and accessible (Fig. 2). Below, we elaborate on how these and other features that teachers mentioned figure into the notion of equity in science education.

Comics Help to Increase the Diversity of Students Likely to Engage with Science

Teachers believed comics, as a genre, to be generally engaging to all their students. In line with research on the motivational benefits of comics (e.g., Norton 2003), teachers consciously chose to use them to introduce science topics from which their students might otherwise shy away. This appeared to be because teachers viewed the comics to package those topics in a format

Fig. 2 Qualities that teachers mentioned about the comics

that youth found appealing. As Megan reported, “I know comic books are very popular in the [school’s] media center for check out. So just by having these [WoV comics] available, I’ve also gotten some students interested in reading about viruses.” Likewise, Keira noted that the comics engaged her middle school students in reading about topics that were more complex than they might otherwise have felt able to tackle. She explained, “Middle schoolers love graphic novels for the most part and so it’s a creative way to get them some in-depth content that they might not really realize they’re reading. So, it’s tricking them into some of the detailed hard stuff that they totally get.”

Another theme expressed in teachers’ interviews was a hope that the comics would specifically motivate certain kinds of students. For example, Audrey, Joel, and Megan identified reluctant or struggling readers as students who would be interested in and benefit from the addition of comics to their science lessons. Audrey and Joel guessed that those of their students who may not have demonstrated strong interest in STEM but who enjoyed reading comic books for leisure, or participating in the arts, would find the comics particularly appealing.

Similarly, 10th grade teacher Therese stated,

I think they are effective for any kid, but I think they are a particular kind of kids who would particularly be drawn to them (...) The kids that like Tolkien, the Sci-Fi fantasy (...). The kind of people who watch Big Bang, would love these. You know what I mean? The ones who play video games and read, you know what I mean? You know which kids I mean. I think that they particularly appeal to them, but honestly I have not met a kid who would look at this and say this is a stupid way to present this information.

Therese later elaborated that she observed her students:

Sit and look at [the comic] for a while, as opposed to a National Geographic where they flip through them and look at the pictures and put it back. So I would say they engage with [the comics] longer than something like [National Geographic], or they wouldn’t have picked it up in the first place.

Teachers furthered their intentions to interest a broader range of their students in the science content by embedding the comics in their instruction and designing accompanying activities. One approach used by most participants was to let students choose which comic to pursue. Research shows that choice is useful for supporting students in developing agency over their own learning, and increasing their identification toward a discipline (e.g., Ames

1992; Pintrich 2000; Stefanou et al., 2004). For example, several teachers offered students choice in which comic story to read for their assignments, so that students could choose according to their interests. Grade 7 teacher, Todd, noted how a series of five comics, each about a different virus, was a feature that enabled him to build choice into a lesson that is otherwise on a single topic. Other teachers offered further student choice through creative projects. For instance, Charlotte encouraged her high school students to choose what visual to create based on their comic reading, which they would present in a “gallery walk” (a presentation format in which students move through a classroom to interact with their peers’ work on display). Some students created posters and others physical models. Eunice had her middle school students rewrite endings to the comic stories they read; Marissa and Sabrina asked their middle school students to write entirely new comic stories based on existing or invented viruses. Each of these strategies appeared intended to create space for individual students to express their multiple identities in the science classroom.

Our one non-teacher participant, a health technician, viewed her school’s health office as a place for informal encounters with STEM topics, particularly with students who would otherwise have negative attitudes toward STEM. Erica kept the comics on the shelf of her waiting room, as an alternative to the usual informational brochures, hoping that they might motivate girls toward STEM careers. Erica reported making efforts to have meaningful conversations with students, and feeling that the comics were a “really good foot-in-the-door to open up those difficult conversation or to start those difficult relationships.” She valued the comics for their ability to make complex information understandable; the manner by which they portrayed “edgy” topics and images of “gross things” that are age-appropriate, and that might also provoke an “Oh that’s so cool!” reaction; and the stories of characters experiencing similar things to the students who visited her office (e.g., for vaccinations). Erica’s example is notable because it reminds us that STEM learning need not be confined to a classroom and that comics can play a role in orchestrating such encounters.

Comics Help to Bridge Science and Students’ Personal Experiences

All participants in this study recognized the importance of building meaningful lessons upon students’ prior experiences and viewed the comics as one tool that enabled them to do so. Whereas some teachers sought the comics as alternative ways to address the topics required by the standards, others were already transitioning to new standards that did not include viruses. These teachers used the comics to explicitly address topics of interest to their students.

Therese, for example, described her frustration that the curriculum requirements outlined in the standards would no longer include viruses, because she has found her students to be deeply interested in the topic:

(...) I spend a lot of time teaching kids things that they are not interested in. “What foods do you get carbohydrates from?” is not interesting to kids. “What is the function of an endoplasmic reticulum?” is not interesting to kids. Viruses are interesting... a lot of the stuff I teach is not the thing [that my students] want to know about biology. That’s just the nature of the state standards. Awhile back I took a day and said ‘If you can think of biology questions I will answer them, we just aren’t going to have an assignment today.’ And we filled the class [time]. You know, they have lots of questions. We had another good chunk of a day where we just talked about Zika and pandemics and epidemics. Those [topics the students propose] are almost always viruses.

Teachers reasoned that students would find the comics interesting because students were already curious about viruses, and because many have had personal experiences with viruses. As Therese explained:

Kids are interested in viruses, they are interested in some of the famous viruses of course, but they’re also interested in how you get them and what you do about them, and they have a lot of misconceptions about them. I thought it would be helpful to have materials [such as these comics] that they would engage in.

Thus for teachers such as Therese, the comics offered another tool in their toolkit for building on students’ prior experiences and perhaps a chance to reach students who are accustomed to and energized by encountering a familiar book format such as the comic.

The manners by which teachers integrated comics into their teaching to create bridges between the science and students’ prior experiences were both explicit and implicit. Ten teachers reported (and three were observed) using the comic as a starting point for classroom discussions, in which they invited students to share their personal experiences, and to relate what they were reading to societally relevant topics. For example, Audrey made connections between the comic stories of historic epidemics and current events, such as bird flu and ebola. We observed Todd leading his grade 7 students in a discussion about their own experiences with contagious diseases, including hospital stays and receiving antibiotics. Similarly, Charlotte reported in her interview leading a dynamic discussion in which her female students shared

their decisions to get the HPV vaccination and also discussed the greater social and economic impacts of viruses (e.g., restriction of meat imports and effects on the price of food).

In each of these examples, participants reported or were observed using the comics as starting points for discussions that allowed students to more deeply consider the relevance of the science to the real world, which is one of Rodriguez's (2015) dimensions of engagement (p. 1043). We argue that the stories told in the comics allowed the topic of viruses to come to life through the characters' experiences and through the situations described. In this sense, teachers were able to use the comic much as a literary text, which, besides offering opportunities to engage with information, can help readers to develop empathy and perspective-taking abilities (Mar et al. 2006; Mar et al. 2009).

How Do Comic Books Support Equitable Approaches to Science Teaching?

The second research question concerns the manner teachers leveraged features of comic books in order to create equitable science learning opportunities for their students. To answer this, we examined how, in their interviews, educators described the roles that they intended for the comic books when integrated into the design of their classroom activities.

At the time of their interviews, all but two classroom teachers had previously incorporated the comics into their classrooms: Hollie had not yet begun to use them at the time of her interview, and Alana had only used only the stickers that accompanied the comics. As well, all but two teachers expressed interest in continuing to use the comics in the future: Alana was neither planning to use the comics nor the stickers; Charlotte was no longer teaching biology; other teachers were experiencing changes in their district standards that left them uncertain about their future curriculum plans. In their interviews, most teachers thus described their aspirations for the role of the comics based on their previous experiences and upcoming plans. Among these roles (Tables 3 and 4), the most frequently mentioned included to (1) engage their students in the topic; (2) help differentiate instruction; (3) provide foundational knowledge; (4) promote students' skills in evaluating multiple sources; and (5) offer an alternative resource to supplement a main lesson.

Likewise, teachers' approaches to using the comics showed a range in the extent to which comics were central to the main activities (Tables 3 and 4). Whereas four participants reported that they only made the comics available for reference or for individual interest during students' free time, and one teacher used the comics in her afterschool program; twelve teachers integrated one or more comics as the centerpieces into multi-day lessons. The

Table 3. Teachers' activities and how the comic was used to support them. These activities were not mutually exclusive, but often used in combination with one another

<i>Kind of activity</i>	<i># teachers observed, or who reported, doing this activity</i>	<i>Description and abilities</i>	<i>Targeted skills</i>	<i>Role of the comic within the activity</i>
Reading and response	6	Groups of 4–5 students read the same comic together, either silently, or aloud. They discuss and respond to a handout of questions about their reading.	Collaboration Summarizing and synthesizing text Interpreting literary devices Critiquing multiple sources of information	Anchor text, informational text
Create a brochure	4	After reading a comic about a particular virus, students create an informational brochure about that virus.	Creating representations Summarizing, synthesizing information	Anchor text, informational text
Special interest	4	Teachers recommend the comic to only certain students, as the topic arises in their informal one-to-one interactions.	Interest-driven independent study	Available to browse during free time
Oral presentation	3	Based on the comic and other resources, students prepare presentations about viruses.	Summarizing and synthesizing text Argumentation	Anchor text, informational text
Whole class discussion	3	Teachers lead a discussion before or after reading the comic to draw connections between students' personal experiences and the science content.	Collaboration Argumentation, explanation	Anchor text
Create a comic	2	After studying viruses and reading at least one of the comics, teachers have students write a short story of a virus in a comic strip format. Students are to include in their narrative details about the virus similar to information found in the comics.	Creating representations, Using literary devices	Anchor text, Model
Invent a new virus	1	After reading the comic, students create their own virus, including in their details the symptoms, means of infection, and means of multiplication.	Present clear ideas appropriate for an intended audience	Anchor text, Model
Write a short story	1	After studying viruses and reading at least one of the comics, teachers have students write a short story of a virus not discussed in the comics. In their narratives, students are to include details about the virus similar to the information found in the comics.	Prediction, hypothesizing	Anchor text, Model

Anchor text refers to a text used to support developing explanations, opinions, arguments, and other artifacts.

Informational text refers to a text used as reference for extracting factual information.

Model refers to an example of an artifact or idea that students can use to guide their production of a similar artifact or idea

Table 4. Profiles of participating educators; how and why they used the comics, and the strengths they perceived in the comics. Thirteen participants were middle school science teachers, and all high school participants were biology teachers. One participant (Erica, indicated by *) was a health technician, not a teacher. Also see table notes below.

<i>Teacher Grade Years of experience</i>	<i>School demographics (%)</i>	<i>Data collected</i>	<i>Comic(s) used (referred to by focal virus)</i>	<i>Are viruses and bacteria typically taught in your curriculum?</i>	<i>Topic(s) of focus</i>	<i>Student activities</i>	<i>Goals for using the comics</i>	<i>Perceived strengths of comics</i>
Audrey	F/R = 25.7 W = 80.7; AI/AN = 0.5; B/A = 3.2; A = 1.2; H/L = 7.0; 2+ = 7.4	SI, CO, SS	Influenza Foot and mouth disease (FMD), Ocean viruses	Yes	Science of viruses Vocabulary	Reading groups Class discussion Comics/ short story creation Create brochure/poster/ other visual	To interest, motivate, and engage students As an anchor text	Easy to understand Has a story Special appeal (for artsy students and non-readers) High quality Informative Engaging Has pictures/ is not wordy Is different
Alana	Title 1	SI	Did not use comic books, but used the accompanying sticker book	N/A	N/A	Use stickers to create a poster	N/A	N/A
G8 5y	F/R = 56.1 W = 61.3; AI/AN = 1.9; B/A = 6.4; A = 4.7; H/L = 15.7; 2+ = 10.0							
Charlotte	F/R = 31.9 W = 76.0; AI/AN = 0.8; B/A = 4.6; A = 1.8 H/L = 9.0; NH/PI = 0.1; 2+ = 7.7	SI	All: assigned different groups different comics	Sometimes, if time permits.	Science of viruses Social, economic impacts of viruses Personal experience with viruses	Create brochure, poster, or other visual Independent research	To reach students with diverse interests As an alternative to an informational text As an anchor text	Is different
G10-12 20y								

<i>Teacher Grade Years of experience</i>	<i>School demographics (%)</i>	<i>Data collected</i>	<i>Comic(s) used (referred to by focal virus)</i>	<i>Are viruses and bacteria typically taught in your curriculum?</i>	<i>Topic(s) of focus</i>	<i>Student activities</i>	<i>Goals for using the comics</i>	<i>Perceived strengths of comics</i>
Celia								
G9–12	F/R = 31.9; W = 76.0; AI/AN = 0.8; B/A = 4.6; A = 1.8	SI	All are available for students to read independently.	No. Comics are sometimes part of a unit on "current science."	Open	Independent reading during free time	To occupy students during their free time	Relatable Has pictures /Is not wordy Connects to kids' existing interests
25+ years	H/L = 9.0; NH/PI = 0.1; 2+ = 7.7							
Erica*								
G6–8	F/R = 25.7 W = 80.7; AI/AN = 0.5; B/A = 3.2; A = 1.2;	SI	All are available for students to read independently.	N/A (Erica is a health technician)	Work of science Personal experience with viruses	Casual reading in the health office waiting room	To interest, motivate, and engage students To open up difficult conversations	Informative Engaging
2y	H/L = 7.0; 2+ = 7.4							
Eunice								
G7–8	Title 1 F/R = 59.3 W = 64.0; AI/AN = 0.4; B/AA = 8.6; A = 3.3;	SI, TA, SS	Students choose a comic to read and answer questions about.	Yes	Science of viruses Work of science Personal experience with viruses Story events	Reading groups Independent reading Comic/short story creation Written Q&A Class discussion	To interest, motivate, or engage students	Free
5y	H/L = 14.3; NH/PI = 0.2; 2+ = 9.2							

Table 4 (continued). Profiles of participating educators, how and why they used the comics, and the strengths they perceived in the comics. Thirteen participants were middle school science teachers, and all high school participants were biology teachers. Also see table notes below.

<i>Teacher Grade Years of experience</i>	<i>School demographics (%)</i>	<i>Data collected</i>	<i>Comic(s) used (referred to by focal virus)</i>	<i>Are viruses and bacteria typically taught in your curriculum?</i>	<i>Open</i>	<i>Written Q&A</i>	<i>Goals for using the comics</i>	<i>Perceived strengths of comics</i>
Francine	F/R = 31.9	SI	Each student reads every comic in the collection.	Sometimes			As an alternative to an informational text Supplemental resource	Has a story
G10-12	W = 76.0; AI/AN = 0.8; B/A = 4.6; A = 1.8							
9y	H/L = 9.0; NH/PI = 0.1; 2+ = 7.7							
Hollie	Title 1 F/R = 73.4 W = 47.1; AI/AN = 0.6; B/A = 11.8; A = 7.0; H/L = 24.4; 2+ = 9.1	SI	N/A	Yes	To address the immune system and HPV To help students who learn in different ways. Engage students who are already interested in comics.	Had not yet done any activities, but typically likes to present a medical case followed by a worksheet	As an alternative to an informational text	Offers alternative format to present same information Are what kids are already interested in. Quick to read, fast-paced story. Not too long.
G6								
3y								
Joel	Title 1 F/R = 73.4 W = 47.1; AI/AN = 0.6; B/A = 11.8; A = 7.0; H/L = 24.4; 2+ = 9.1	SI	All are available for students to read independently	No	Open	Independent reading during free time	Interest/motivate/engage students To reach students with diverse interests	Easy to use Special appeal (for students inclined toward the arts, and disinclined toward reading) High quality
G8								
16y								

Teacher Grade Years of experience	School demographics (%)	Data collected	Comic(s) used (referred to by focal virus)	Are viruses and bacteria typically taught in your curriculum?	Topic(s) of focus	Student activities	Goals for using the comics	Perceived strengths of comics
Jocelyn G9-12 15+ years	N/A	SI	All are available for students to read independently	No	Open	Independent reading during free time Given to students she thought would enjoy them	To interest, motivate, and engage students	Fun reading
Keira G7 23y	F/R = 25.7 W = 80.7; AI/AN = 0.5; B/A = 3.2; A = 1.2; H/L = 7.0; 2+ = 7.4	SI	All: assigned different groups different comics	Yes	Vocabulary	Reading groups Oral presentation (includes gallery walk, whiteboard talks, slideshows)	To interest, motivate, and engage students To reach students with diverse interests As an anchor text	Special appeal (for differentiated students) Is different Connects to kids' existing interests
Lydia G7 5y	F/R = 42.1 W = 72.1; AI/AN = 1; B/A = 5.1; A = 3.5; H/L = 11.1; 2+ = 7.2	SI	All: assigned different groups different comics	Yes	Introduction to microbes	Independent reading with guided note-taking	To interest, motivate, and engage students As an anchor text	Free Engaging
Lorena G7 10y	F/R = 38.1 W = 71.1; AI/AN = 1.1; B/A = 5.1; A = 2.4; H/L = 12.2; NH/PI = 0.2; 2+ = 7.8	SI	All: assigned different groups different comics	Yes (will change as district standards change)	Science of viruses	Reading groups Create brochure/ poster/other visual Oral presentation (includes gallery walk, whiteboard talks, slideshows)	To reach students with diverse interests As an alternative to an informational text	Relatable Has a story Has pictures/is not wordy Is different Connects to kids' existing interests

Table 4 (continued). Profiles of participating educators, how and why they used the comics, and the strengths they perceived in the comics. Thirteen participants were middle school science teachers, and all high school participants were biology teachers. Also see table notes below.

<i>Teacher Grade Years of experience</i>	<i>School demographics (%)</i>	<i>Data collected</i>	<i>Comic(s) used (referred to by focal virus)</i>	<i>Are viruses and bacteria typically taught in your curriculum?</i>	<i>Topic(s) of focus</i>	<i>Student activities</i>	<i>Goals for using the comics</i>	<i>Perceived strengths of comics</i>
Megan	Title 1 F/R = 73.5; W = 45.8; AI/AA = 1.6; B/AA = 15.9; A = 5.6; H/L = 23.7; 2+ = 7.5	SI, CO, TA, SS	Student groups choose a comic to read and report on	Yes, but this will change as district standards change	Science of viruses Work of science History of science Story characters	Reading groups Create brochure/poster/other visual Oral presentation (includes gallery walk, whiteboard talks, slideshows) Written Q&A	As an alternative to an informational text As an anchor text	Curriculum alignment It's physical (not digital) Mature topics/does not descend High quality Informative Has pictures/is not wordy Connects to kids' existing interests
Marissa	F/R = 38.1 W = 71.1; AI/AN = 1.1; B/A = 5.1; A = 2.4; NH/PI = 0.2; 2+ = 7.8	SI, CO, TA, SS	All: assigned different groups different comics	Yes	Science of viruses	Reading groups Comic/short story creation	To interest, motivate, and engage students To reach students with diverse interests	Visually appealing Easy to use Engaging Has pictures/is not wordy
Sabrina	Title 1 F/R = 59.3 W = 64.0; AI/AN = 0.4; B/AA = 8.6; A = 3.3; H/L = 14.3; NH/PI = 0.2; 2+ = 9.2	SI, TA	Students choose two comics to read and use to respond to comprehension questions.	Yes	Introduction to viruses and how they multiply Story events and characters Comic format	Reading groups with guiding questions Invent a virus and create a comic about it	To extend a unit To interest, motivate, or engage students	Visually appealing Easy to use

<i>Teacher Grade Years of experience</i>	<i>School demographics (%)</i>	<i>Data collected</i>	<i>Comic(s) used (referred to by focal virus)</i>	<i>Are viruses and bacteria typically taught in your curriculum?</i>	<i>Topic(s) of focus</i>	<i>Student activities</i>	<i>Goals for using the comics</i>	<i>Perceived strengths of comics</i>
Therese								
G10	F/R = 53.3; W = 59.3; AI/AN = 1.0; B/A = 8.0;	SI, CO, TA, SS	Influenza EHV (Ocean Viruses	Sometimes	Science of viruses Story events Story comprehension	Independent reading Written Q&A	As a supplemental resource	Informative Engaging Is different Connects to kids' existing interests
17y	A = 6.8; H/L = 19.4; NH/PI = 0.1; 2+ = 5.5							
Todd								
Title 1		SI, CO, TA, SS	Each student is required to read about 3 viruses independently	Yes	Facts about viruses Story events Personal experience with viruses	Independent reading with comprehension questions Class discussion	To interest, motivate, or engage students	Offers different choices Quick to read High quality Informative Engaging Has pictures/ is not wordy Is different Connects to kids' existing interests
G7	F/R = 73.4 W = 47.1; AI/AN = 0.6; B/A = 11.8;							
6y	A = 7.0; H/L = 24.4; 2+ = 9.1							

For **Data collected** column, SI = survey & interview; CO = classroom observations; TA = teaching artifacts; SS = student survey
School demographics are from the 2015–2016 District Statistics and Evaluation report, retrieved from lps.org. F/R = qualify for free or reduced lunch; W= White; AI/AN = American Indian/Alaska native; B/AA = Black/African American; A = Asian; H/L = Hispanic/Latino; NH/PI = Native Hawaiian/Pacific Islander; 2+ = 2 or more races

activities we documented from our participants reflect many of Rodriguez's (2015) guidelines for addressing engagement, equity, and diversity in science teaching and learning (Table 5). Below, we describe four specific categories of approaches to integrating comics and discuss their implications for equitable science teaching.

Table 5. Examples of how teachers used the comic books in their instruction to address guidelines under the dimensions of engagement, equity, and diversity practices (content in the left column is quoted from Rodriguez 2015, p. 1043)

Engagement

Guideline	Examples of how teachers addressed this guideline
Content is socially relevant	<p>Teachers highlighted the relevance of viruses in society:</p> <ul style="list-style-type: none"> • During class discussion, Audrey highlighted relationships between contemporary outbreaks, such as bird flu and Ebola, and the historic epidemics covered in the comics. • Megan assigned her students the question: "How can we win the war against viruses?" Worded as a call to action against a common foe and a problem that we must work together to solve. • Todd facilitated class by highlighting the personal relevance of the topic: "Has anyone been to the hospital for being sick?" and then followed up with the questions, "What did you have?" "Did you take an antibiotic?" By having students share with their peers highlights that experiences with viruses are shared. • Charlotte discusses the social and economic impacts of viruses (e.g., how foot-and-mouth disease restricted meat imports and subsequently affected the price of food). • Celia sees teaching viruses as a way of addressing what she calls a "current science" curriculum. • Francine makes an effort to fit the comics into her classroom time, despite the topic not being officially being part of the curriculum, because she feels it helps to prepare students for future jobs. • Therese ties the comics into a discussion of Zika and the concept of epidemics and pandemics. <p>Teachers connected viruses to personal interests:</p> <ul style="list-style-type: none"> • Therese noted her choice to use the comics because she knows her students are interested in them. • Erica ties what students read in the comics to what they are experiencing in her health office.
A variety of pedagogical strategies are used within every lesson focused on student-centered and collaborative learning	<p>Teachers incorporated interdisciplinary activities into their lessons:</p> <ul style="list-style-type: none"> • Audrey had students use Comic Life to make a poster about a virus or bacteria.

Table 5 (continued). Examples of how teachers used the comic books ...

	<ul style="list-style-type: none"> • Eunice had students create a 6-panel comic that either changed or amended the ending. • Francine invited students to be critical about the value and effectiveness of the comic book by prompting them to respond to such questions as: "What did you learn about the virus? What was interesting? What did you think of the format?" • Multiple teachers assigned different comic books to different student groups, and then had groups teach each other through presentations, student-generated comics, posters, etc. • Charlotte had students in groups present about a specific virus to present to the class in a "gallery walk" format • Keira also jigsawed the viruses. Reading groups (four to six students) were assigned to read and discuss a different story. Over the course of a week, they presented what they learned to the rest of the class. • Initially, Lorena has two to three students in a reading group read an assigned story/different virus. These students had to pick out information about the nature of their virus, following guiding questions on the board. Groups then presented to the class.
Students are provided with some choices for conducting activities and/or projects	<p>Teachers gave student groups choices of which comic to read:</p> <ul style="list-style-type: none"> • Megan had her grade eight students team up and choose one of five comic stories to read. • Todd and Eunice allowed students to select and read comics of their choice, sometimes having students work individually, and other times having them work with a partner of their choosing. • Lorena asked her students to create a brochure of a virus of their choice, including viruses that were not in the comic.
Students work in small groups (not more than three to four per group)	<p>Teachers organized students into reading groups:</p> <ul style="list-style-type: none"> • Marissa had her grade 7 students count off to form groups of 5, in which they read the comics and responded to questions in a reading guide. • Sabrina's 7th–8th grade students paired up to read a comic. Each pair then shared, or filled each other in on details of what they read with another group of students. • Megan had grade eight students from reading groups of 2–5, which later collaborated to create posters based on the comic they had read.
Students have choices for representing knowledge (i.e., presentations, posters, skits, video narratives, lab reports, and so on)	<p>Teachers offered students freedom in how to design artifacts based on their reading:</p> <ul style="list-style-type: none"> • Audrey had students use Comic Life to create unique posters.

Table 5 (continued). Examples of how teachers used the comic books ...

	<ul style="list-style-type: none"> • In addition to including in their presentations required information on the virus, Charlotte prompted her students to share something they found interesting and to find their own images of the virus and the researchers. • Charlotte used the comic as one example among other media in which her students could present information from their research projects. • Eunice had her students propose alternative endings or additional chapters in comic book format to the comic they had read. • Sabrina had students use six empty panels to create their own comic strip stories. • Megan had student teams create a poster using whatever format they desired, in which they were invited to share what they found most interesting.
<i>Guideline for engagement that was not apparent in this study:</i>	<ul style="list-style-type: none"> • <i>Students are encouraged to access and/or work with community leaders/elders/family members</i>

Equity

Each student has equal access to participate (e.g., accommodations are made for girls, ELL's and students with disabilities to have equal opportunities to participate in and out of classroom activities/discussions)

Modeling how to read the comic, worksheets to scaffold reading practices.

- Depending on whether she had special education students in her class, Audrey either had her students use the web application, *Comic Life*, to make posters, or to create their own four to ten panel comics on paper.
- Audrey first elicited students' prior knowledge of comics by asking what they knew about comic books. She scaffolded their reading by introducing several vocabulary words (tale, epidemic, pathologist, plague, 1918 plague, pandemic) and modeled how to read it by reading a portion of it aloud.
- When she noticed the difficulty experienced by one of her two classes of students in understanding that a character in the comic was a personification of a virus, Lorena provided them with a graphic organizer to help.
- To ensure that her students could successfully navigate the comic, Sabrina provided a reading guide for with scaffolded prompts such as "Illness being discussed: _____ (found at beginning of comic)" and "Summarize the Comic (who, what, when, where, why)."
- Therese and Todd provided a worksheet to help students extract relevant information from the comic. Questions were both about content knowledge ("What is the ecological role (job in nature) about the virus?" "Name two facts about your virus.") and about the comic's narrative ("What did the creature later turn into?" "What was the setting of your story?" "What was the conflict of your story?").

Table 5 (continued). Examples of how teachers used the comic books ...

	<ul style="list-style-type: none"> • Megan gave students a handout for making a poster as a model of what type of information students should include in their own posters. • Marissa gave students a handout with examples of details students should include in their own stories.
Differentiated instruction is provided for ELL's and students with disabilities	<ul style="list-style-type: none"> • Marissa, Keira, and Joel noted that their choice to use the comics was to reach their ELL students, whom they suspected would have an easier time understanding the comics than they would understanding a traditional science text.
Accommodations are made for students with limited access to resources/ technology	<ul style="list-style-type: none"> • Printed comics were freely distributed to teachers at professional development events. Digital formats are also freely available online.
<i>Guidelines for equity that were not observed in this study:</i>	<ul style="list-style-type: none"> • <i>A variety of grouping approaches are used (e.g., ELL's with native speakers, same gender grouping, mixed ability groupings).</i> • <i>Accommodations are made for assessing students' knowledge growth (e.g., visual aids, bilingual vocabulary, translation help, audio devices, and so on)</i> • <i>Accommodations are made to make science classroom accessible to parents/guardians/ community leaders and elders (e.g., providing a translator; printing newsletter in more than one language; providing transportation; providing babysitting, and so on).</i>

Diversity

Content is culturally relevant

Teachers used both the topic of viruses, and the comic book format to encourage cultural relevance

- In introducing *The Frozen Horror*, Audrey discusses the relevance of viral diseases to current events, and highlights the phrase "1918 plague" in her vocabulary list. This situates the relevance of viruses within cultural-historical and not just current events.
- Audrey connected the story in *A Frozen Horror* to a larger theme of native folklore, and its role in preserving and transmitting a community experiences.
- Audrey recognized comic books as a form of literature from youth culture that can "hook" her students' interest.

Table 5 (continued). Examples of how teachers used the comic books ...

<p>Contributions of non-Western and/or female scientists and are also highlighted.</p> <p>Students are encouraged to tie cultural/ethnic backgrounds to investigations/activities/discussions</p>	<ul style="list-style-type: none"> • Charlotte used the comics format to show her students that informational sources can be diverse, and need not be limited to Wikipedia and journal articles. Similarly, Megan used the comics to engage her students in a discussion of the reliability of computer-based resources. • After they read the comic, Francine asked her students "What did you think of the format?" to encourage a meta-awareness of what and how different formats communicate information. • Female and under-represented characters in the comic books represent a range of roles, including scientists. • Charlotte highlights the relevance of female perspectives when discussing the HPV comic by inviting female students to talk about their experiences with HPV vaccination. • Eunice noted that a strength of the comics is that they connect to, and help to elicit students' personal experiences and participation, who may not typically have engaged. She noted how girl who struggled academically once raised her hand during class discussion of the comic to share that she had foot-and-mouth disease. • Erica made the comics available in her health office in particular to interest girls in STEM.
<p><i>Guidelines for diversity that were not apparent in this study.</i></p>	<ul style="list-style-type: none"> • <i>Groups are culturally diverse (even if class appears homogeneous, there is always ethnic roots diversity).</i> • <i>Assessments are culturally sensitive and inclusive (e.g., over representation of males, masculinity or "hero narratives"/conquest over representation of Western or middle class narratives avoided.</i> • <i>Students' family composition (e.g., single parent, same sex parents), religion, immigration status, sexual orientation, ethnicity and/or SES are respected and seen as resources for building community and enhancing learning.</i>

By Integrating Other Disciplines

One way that teachers used the comics to interest students in the science topics covered was by creating lessons that incorporated disciplines of interest beyond science. To do so, some teachers drew on instructional practices from the language arts. For example, 12 teachers created multi-day activities in which the comics served as *anchor texts*. In language arts education, anchor texts are resources aligned with the curricular theme and used to support activities that engage students in developing explanations, opinions, arguments, and other artifacts. As anchor texts, the comics were central in *group reading and response* activities, during which small groups of students

read an assigned comic or one of their choice—either aloud or silently—and responded to a set of comprehension questions. This activity structure modifies the literature circle typical in language arts (Lin 2002) but uncommon in science education. While to some extent, all teachers' comprehension questions emphasized students' understanding of the science content (e.g., the nature of viruses), others encouraged students to not only extract, synthesize, and summarize factual science information from the comic, but to also reflect on the story's characters and structure. Class conversations about the comic moreover had students go beyond the science content to exploring the comics' historical, futuristic, fictional, and societal themes.

As with anchor texts in language arts instruction, the comic's narrative was a critical entry point into the ideas and practices that teachers wished to introduce to their students. For example, Audrey, who explicitly described the influence of her prior 16 years as a language arts teacher on her approach to teaching science, used the comic's narrative to introduce ideas she aimed to address later in her unit: "I use these [comics] for prior knowledge purposes, so I can set up the virus scene ahead of time and give kids some prior knowledge." We observed her in class asking students such questions as: "What do you think of those characters? What do you think of viruses? What do you know about viruses?" as a way of giving her students a starting point for considering scientific ideas.

Audrey also sought to immerse her students in science topics just as she might in a compelling fictional narrative: "Even in teaching science the last 8 years, I incorporate language arts writing into what I teach. I'm always looking for hooks." The comics, she noted, are "very multicultural," adding "You can tie things in a lot. It's written well, and I think it's a great hook for kids." In discussing *The Frozen Horror* with her students, we observed how Audrey highlighted the comic's narrative about a native legend to demonstrate to her students how certain communities have used folklore to commemorate past experiences with infectious disease. In this way, Audrey had her students engage with non-Western-oriented understandings of disease. Her use of a KWL (What I Know, What I Want to Know, What I Learned) chart guided her students in constructing their understanding of their reading by activating their prior knowledge (Ogle 1986).

Seven teachers, taking inspiration from the comic's format, devised literary, and artistic activities, such as creating original short stories and comics, inventing fictional viruses, and preparing presentations that, as with the comics, emphasized the integration of verbal and visual information. Their assignment requirements likewise aligned with criteria in nonscience domains. For example, we observed Megan distribute a handout to her students that specified that the informational posters they were to create "should be colorful, creative, and easy to read," criteria that are typically taught in graphic design, although also important in science communication. Likewise,

Sabrina, who had her grade 7–8 students invent viruses and create comic strips about them, specified in a handout that their “Story must flow and be creative.” Such lessons emphasized the development of new literacies, which include how to read and interpret diverse texts and how to communicate information effectively. Moreover, the teachers’ activities and assessment criteria demonstrate the intentionality with which they attempted to authentically engage multiple disciplinary practices and encouraged understanding ideas through multiple disciplinary lenses. The comics enabled teachers to create activities that valued knowledge and skills beyond science, which research suggests is an effective strategy for diversifying participation (e.g., Warren et al. 2001; Lee 2002; Rosebery et al. 1992).

By Using Comics as Tools for Scientific Modeling

Another way that teachers promoted equitable science learning was by leveraging the comics, which they had already identified to successfully capture the interests of diverse learners, as tools for engaging their students in scientific modeling. Scientific models are evidence-based representations that abstract aspects of a system in order to make sense of, explain, and predict phenomena (Schwarz et al. 2009). They can be either drawn, written, or acted out, and can represent externalizations of an individual’s mental models of phenomena; consensus models, tested and agreed-upon by groups of people; and teaching models, used to clarify learners key aspects of a system (Gobert and Buckley 2000). Models represent key elements and behaviors of a system, as well as rules for their interactions (Lesh & Doerr 2000). By this definition, narratives also serve as models, as they likewise define actors, behaviors, and rules within a specified world.

As with other models, narratives enable readers to run mental simulations of possible scenarios in order to make predictions about narrative outcomes (Jonassen and Hernandez-Serrano 2002). Along these lines, we observed teachers in our study use the comic’s narratives as tools for making scientific predictions. In her handouts, for example, Therese instructed her grade 10 biology students to read “The Frozen Horror,” and to reflect on questions including: “Why did the scientist want tissue samples from people? What did the creature later turn into? Why did the creature appear to change its form?” We also observed how Therese had her students read “The Never Ending Battle,” which describes the role of viruses in maintaining the Earth’s atmosphere by controlling algal blooms in the ocean and asked them such questions as “What would happen to humans if *E. huxleyi* disappeared?” These kinds of questions can prompt students to provide scientific context to characters’ actions, to give scientific explanations of the story’s outcomes, and to make predictions backed by scientific evidence. The questions thus have students demonstrate their understanding of the comic’s

narrative as a model of the scientific world that it references. By situating these reasoning tasks within the comic's narrative world, students can mentally test likely behaviors of viruses in different situations and predict and explain such things as how viruses might spread, how a vaccine might work, and what might be possible alternative scenarios of cause and effect. The ability to use models to make predictions, as Therese had her students do with the comic's narrative, is one of the core practices of scientific modeling (Schwarz et al. 2009).

Other teachers encouraged students to use the comics to support their construction of scientific models. For example, after her student groups read and shared the comic stories among themselves, Eunice distributed a handout that instructed her middle school students to compose alternative endings to the stories. Doing so can engage students in reasoning about potential alternative scenarios within the constraints and possibilities of the scientific and narrative world, similar to how scientists reason about possible outcomes by manipulating components of a model within the rules of their behavior. In her interview, middle school teacher Sabrina similarly described a handout she used to direct her students to take inspiration from the comics to invent their own novel viruses and comic strips about them. Having thus been introduced to the characteristics, behaviors, and impacts of viruses through the comic's stories, students had evidence upon which to construct new stories. They could moreover use those comic stories as bases for their own stories by revising certain aspects and comparing outcomes. Comparing models and using evidence to revise and build new models are also core practices of scientific modeling (Schwarz et al. 2009).

Some researchers suggest that a meta-awareness of scientific modeling should be central to science education (Schwarz and White 2005). We do not know whether students in our study were aware that what they were doing was scientific modeling. We also acknowledge that explicit model-based teaching and learning encompasses far more than the practices we observed (e.g., Clement 2000; Lehrer and Schauble 2006). Nevertheless, we maintain that the activities we observed in teachers' classrooms had value in engaging students in modeling practices, including exploring, constructing, and revising one's knowledge. These activities moreover demonstrated teachers' abilities to use comic books' unique qualities as opportunities for engaging students in scientific practices, and thus in deeper science learning.

By Promoting the View of Comics as Science Texts

A third way that teachers used comics to support equitable science learning opportunities was by adopting an expanded view of science literacy: one that encompassed multiple kinds of texts and representational practices. Audrey explained the pedagogical value of having science translated

into non-professional textual forms for both connecting to kids' existing interests and for helping them realize that there are multiple ways of communicating "real science."

[When students] realize "oh my gosh you could write a comic book on viruses?" I think that's kind of a cool idea. I mean, you know, how original is that? So, and then, the fact that it has some stories that go along with the comics that are more factual, essays, I just think that's kind of a good piece for kids to see real science. And, I think the pictures are great.

Certain teachers' lessons explicitly introduced the comic to give their students practice in critiquing and evaluating diverse sources of science information. For example, Megan reported in her interview and was also observed assigning her grade 8 students a standard textbook chapter to read alongside the comic. Recognizing the unique challenges of the comic format, Megan's handout assigned comprehension questions that not only asked her students to probe the meaning of the text but to also attend to the pictures, which mixed realism, stylization, and sometimes anthropomorphized depictions (e.g., "What does the virus look like?"). She moreover asked for her students' opinions on the format, starting a discussion about what constitutes a reliable source of information, and whether comic books count.

Francine likewise had her high school students write not just about what they learned about viruses following their reading of the comic, but also asked "What did you think of the format?" to encourage them to reflect on the validity of the comic as a source of information. Charlotte similarly reported using the comics to develop students' abilities to use multiple alternative resources and to communicate in diverse media. While primarily using the comics in her biology class, she had also shown the comic to her high school chemistry students as an example of an alternative medium they might use to present their research projects. She also used the comics to substitute typical information sources, such as Wikipedia and scholarly journal articles, as well as to encourage her students to use various ways of thinking in order to make sense of challenging topics. Charlotte ultimately organized a gallery walk, during which her high school students displayed artifacts they had created based on their independent research on viruses. Reflecting during her interview, Charlotte stated that the next time she uses this activity, she would encourage her students to use an even greater array of multimedia in their displays (images from the comic, for instance), as well as multiple other formats, such as posters, collages, and 3D models.

These activities exemplify ways to support students in developing meta-textual awareness. Moreover, by cultivating an appreciation of the variety of modes of science communication and the diversity of skills that are valued in

science, these teachers attempted to expand students' view of what counts as a scientific text and what kinds of skills make one able to do science.

By Creating Opportunities for Teachers to Investigate and Improve Their Instruction

For at least three teachers, the choice to use comics raised questions about what makes effective curriculum artifacts. Whereas Therese had used *World of Viruses* materials in the past, she had not yet used the current materials at the time we requested an interview. Once reminded of them by our request, she approached the comics as an opportunity to investigate questions about her own instruction. To do so, she designed a classroom experiment to explore the relative effectiveness of comics vs. essays. After her interview and our observation of her subsequent classroom study, Therese shared a written report of her findings. In it, she wrote: "Viruses are not specifically mentioned in the state standards for Biology, but they keep coming up tangentially: whether they are alive, whether the definition of life in the Biology text is accurate, why eukaryotic cells have nuclei to protect their DNA, and how the shape of an antibody makes it specific for a particular virus. I decided to try out the virus materials. As I looked at them, I noticed that each 10-page virus comic was accompanied by 2 pages of plain text that contained the same information. When I checked with my contact at [Author's university], I found that the field tests of the materials were focused on engagement rather than on effectiveness. I thought I could find out whether there was a difference in effectiveness between the two types of content."

Specifically, Therese wished to know whether the format of information would be better grasped by her students depending on their gender or the languages they spoke at home. In her study, Therese directed half of her students to read a comic and the other half to read the essay written to accompany that same comic and that presented the same factual science information. Following their reading of each material, the students responded to the same set of comprehension questions. As stated in her report, she expected her ELL students to show greater proficiency after reading the comics than after the reading the essays, due to the comics having pictures supporting the text. This assumption is one that is likely shared by many teachers, and that guides the decisions they make about how to present instructional materials. For Therese, the comics were a chance to formally investigate these assumptions, and through them, she found the situation to be more nuanced and complex than she expected. For example, Therese reported how her English-speaking students performed better when reading the comic than when reading the essay. Meanwhile, the opposite was true for ELLs, who performed better when reading the text than when reading the comic. In her report, Therese speculated on the meaning of these findings:

What I thought this meant (if it is not a statistical blip) is that reading the straightforward text, without distractors, might help kids struggling with language. Maybe it's too hard to focus on the words and pictures at the same time? For kids who are comfortable with the language, having all of the pictures might help solidify it as they read.

While it may not be possible to draw definite conclusions from Therese's study, her initiative demonstrates her commitment to developing a repertoire of tools for reaching students with different backgrounds and language proficiencies. This in itself is a laudable goal, particularly as it is often too easy for educators to blindly rely on traditional, but less adequate modes of instruction.

What Challenges Do Educators Encounter in Using Comic Books in Their Teaching?

Thus far, we have discussed the potential that teachers view in comics and the manners in which they take advantage of those aspects to promote equitable science learning opportunities. However, to take proper advantage of their potential, teachers must overcome negative attitudes toward comics, the unique literacy challenges of comics, and the dilemma of incorporating comic books as curriculum artifacts that both address students' interests and align with curriculum requirements. Our third research question addresses these challenges, which we discuss in turn below.

Questioning the Educational Rigor of Comics

Although academics have pointed out the sophisticated literacy practices surrounding popular culture artifacts, including video games, fanfiction, and comic books, there is still resistance to viewing such artifacts as belonging in formal educational settings (Hutchinson 1949; Millard and Marsh 2001). Among our participants, we noted that while all recognized some value in the comics, at least two clearly struggled to reconcile these popular culture artifacts with their views of academic rigor. Jocelyn, for example, viewed comics as "More for fun reading than educational," and accordingly kept them available on her classroom's shelves, handing them to her high school students whom she believed would be interested. Likewise, Joel expressed a bias toward written over pictorial communication, predicting that his students would "look at pictures but not read the words, and I think it's the reading that they actually learn stuff more than the pictures." With skepticism that a teacher could do anything of educational use with the comics, Joel noted that students "would have to take [the comics home] with them because it's a big read, and so I couldn't really institute [comics] for the curriculum."

Later, Joel adds that a teacher plays an important role in making comics effective:

Just like anything, if the teacher doesn't teach it and enforce it and assign it, [students are] just not going to get much from [the comics].... But they might learn stuff from the pictures too, but if a teacher doesn't really make it a part of the curriculum [then students will not learn from the comics].

While a minority among our sample of participants, Joel and Jocelyn's opinions are shared by teachers and administrators beyond this study. They remind us that whether teachers adopt classroom innovations, and the ways by which they do so, are governed by values and beliefs ingrained in everyday practices and reinforced by the systems in which these exist (Pearson and Somekh 2006; Somekh 2008).

Overcoming Difficulties in Understanding the Comics Format

Accessibility is critical to creating equitable learning opportunities (Rodriguez 2015), and some teachers explicitly identified and addressed specific accessibility issues in our study. To understand a comic book requires coordinating multiple literacy skills, including reading panels in the correct order, decoding symbols, interpreting visual metaphors, and distinguishing fictional from nonfictional aspects of the narrative.

Charlotte and Lorena observed several kinds of struggle among their students and 17 of their students also noted this in their survey responses. Sometimes, their confusion was with the vocabulary, which crossed between formal scientific language and informal expressions. Other times, students' struggles were with interpreting the small handwritten print that is traditional in comic books. Still other students struggled to follow the sequence of panels, as one student reported, "[The comic] was hard to follow if you have never read a comic book before." One high school teacher's decision to use comics was met with rebuke by one student, who was particular in his view toward the place of reading in science. Specifically, one of Todd's students noted in his survey that he wished the comics had been presented in a different class, as his expectation of science class was that there would not be so much reading.

Certain teachers had strategies for addressing students' difficulties. For example, Lorena reported that her students had difficulty understanding visual metaphors, and specifically, that a female character in *The Curse of the Tree-Man* comic was not actually a human character, but a personification of HPV. She therefore created a graphic organizer to help her students understand that the female character is the virus. Other teachers circumvented

similar potential challenges by preparing students to read this novel format. For example, we observed that Audrey introduced the comic by eliciting students' existing ideas about comics books, asking them, "What do you know about comic books and the tales they tell?"; thus, giving her students opportunities to connect their personal reading experiences to this school reading experience. She then modeled how to read the comic by reading a portion of it aloud to her students, offering them a list of vocabulary words to scaffold their comprehension.

Finding a Place for Comics Despite Changing State Standards

Fourteen teachers reported encountering a third challenge, which concerned external barriers to introducing new materials. In their surveys, nine teachers indicated the lack of time to plan lessons based on new material, and seven teachers pointed out that the lack of flexibility in their school district's curriculum standards to "somewhat" or "very much" limit their abilities to introduce new materials. Two of these teachers identified both the lack of time and flexibility as barriers (Fig. 3). The barrier that teachers rated as having the greatest impact, however, was the time needed to address district objectives. Three teachers additionally reported in their interviews that due to the removal of topics on viruses and bacteria from their districts' standards, they were uncertain about whether they would use this particular set of comics again.

However, at least three other teachers viewed the importance of topics of viruses to science, and students' personal interest in it to be sufficient justification for formally addressing it through their instruction. As Therese

Fig. 3 Teachers' ratings of severity of barriers faced in attempting to use new resources in their classrooms

noted, “realistically, the objectives do not include viruses. I don’t think the word is ever mentioned in the state standards. So, (...) it just ends up getting pieced in [to her lessons because] the kids are interested in them.”

Celia, who recognized the topics covered to be important and valued their “kid-friendly” presentation, used the comics as morning warm-up reading for her Bright Lights students, a summer program focused on nanoscience. Francine moreover saw its relevance for preparing her high school students for the future:

There’s no specific place [in the curriculum in which I address viruses], but I do feel like [virology is] a growing issue and a new area that you know, we say we’re teaching for jobs that aren’t created yet and I think that this is an area that when these kids are grown up, there’s going to be research going on.

Francine described how she and her colleagues have tried various ways of incorporating comics, and the topic of viruses into her curriculum, such as around the topics of DNA, the classification of organisms, and an activity called *Is it alive?* in which “kids would go around and look at objects or get descriptions and try and decide if it’s living or not living. Viruses are a neat thing to put in there.”

Discussion and Conclusions

The Roles of Comic Books in Equitable Science Instruction

Knowledge of what successful teachers do to offer students meaningful learning opportunities benefits both research and practice (Ladson-Billings 1995a). This study documents the ways that educators, who were committed to equitable science teaching, incorporated comics into their instruction with the goal of broadening the diversity of students who take interest in science. By exploring comic books as curriculum artifacts, and their potential roles in meeting science teachers’ classroom equity goals, this study contributes to the general literature on teachers’ adoption of classroom innovations, and joins others’ efforts to understand science teachers’ practices around issues of equity (e.g., Johnson 2011; Nam et al. 2012; Laughter and Adams 2012). It also offers specific insights on how comics are used in science teaching.

Among other features of effective teaching is an acknowledgement of students’ different interests and abilities and a repertoire of strategies for engaging diverse students with key disciplinary ideas and practices. This study argues that comic books can be tools for effective teaching, and when utilized appropriately, they can be uniquely successful in helping teachers

address issues of diversity, equity, and engagement in science learning. For instance, in choosing a popular reading material in which many students already take an interest; in choosing comics that feature diverse characters and storylines; and in incorporating these comics into their formal classroom settings, teachers hoped that their diverse students might take an interest in the subject matter, find ways to identify with it, and thus deepen their engagement in science. Their actions reflect a recognition of the importance of creating bridges between students' formal learning and their out-of-school interests and experiences (National Research Council 2009).

We observed a range of manners by which participants created these bridges. For instance, they designed classroom activities that were both individual and collaborative and ranged from reading comprehension questions that had students identify key science content ideas, or to reflect on the significance of visual metaphors and narrative elements, to constructionist projects that had students use the comic as a resource for informing the expression of their own understanding, or as a reference for constructing new models of viruses. Moreover, we observed ways that teachers incorporated multiple disciplinary lenses into their lessons and assignments, including sociology, art, design, and literature, in order to broaden the reach of particular science practices, such as scientific modeling.

Other participants leveraged the opportunities that the comics introduced to integrate inclusive language practices into formal science instruction. Science is a specialized system of discourse that requires a grasp of concepts and terminology not always within reach for novices (Hicks, 1995/1996; Krajcik et al., 1998; Lee and Fradd 1998; Lemke, 1990; Santa & Alvermann, 1991). It can be especially alienating for learners from minority language groups, who already struggle to engage in the everyday discourse of their majority language communities (Brown, 2006). For such students, using comics in the classroom can validate everyday language practices within formal science instruction. Comics can create opportunities for teachers to bridge students' everyday experiences and explanations with the concepts and formal language of science, a practice that can invite more diverse participation, and thus, create more equitable science learning opportunities for all (Lee and Fradd 1998; Moje et al., 2001; Schoerning 2018). Many of the participants in this study recognized this opportunity and took advantage of it, to varying extents, through the choices they made to incorporate comics into their instruction.

Altogether, our findings build on our understanding of the dynamic relationship between teachers and their curriculum tools. No doubt, teachers' activity designs were inspired by features of this particular comic collection, including its authenticity to the medium and to science, the extent of its content, and its relatability to youths' existing interests. At the same time, these teachers showed a range of PDC. Whereas all teachers showed a

commitment to equity in their science teaching by their willingness to create opportunities for all students to participate in meaningful science, it is likely that personal epistemologies, values, and teaching experiences played critical roles in their abilities to both recognize and harness the potential of the comic books to teach science. These prior beliefs and experiences may account for the differences in teachers' approaches to using comics in their instruction.

For example, Audrey pointed to her prior experience and values as a language arts educator to explain why she viewed comics as an opportunity to infuse language arts into her science teaching. Other teachers used the comics as starting points for students to create novel viruses, which suggests their emphasis on modeling as a scientific practice. Still other teachers used the comics as means to open conversations with students about their personal experiences, an approach that aligns with constructivist views of science learning.

That certain teachers used the comics as optional supplementary resources, whereas others incorporated them as central resources in learning activities, may indicate differences in the value that teachers place on informal educational texts and their place in classroom instruction. Alternatively, differences in educators' approaches could simply reflect differences in the external constraints they faced in realizing their goals with the comics. Some teachers were working within limitations imposed by their state standards, while others may have felt resistance from their schools' administration. Yet, in their desire to realize the potential they saw in comics, these participants may have sought alternative means to bringing the comics to their students, such as by making them available after exam periods, or in after-school programs.

Further research, including more systematic observations, in-depth interviews, and surveys, would allow us to more deeply understand the specific reasons that teachers differed in their apparent pedagogical design capacities.

Limitations

A major limitation of this study is the generalizability of its findings beyond our participants. All of the teachers in our sample were already open to using these comics and had taken initiative to request them from us. In their surveys, the majority of our participants reported few barriers to incorporating new materials into their instruction and an inclination to do so regularly. Some even adopted the comics in spite of perceived barriers. For example, Charlotte noted that a lack of planning time, as well as district objectives both "Very much limit" her ability to use new resources, but

nonetheless reported using new resources “In almost every class.” These teachers’ openness to incorporating non-traditional curriculum materials to address core content, their attempts to tie lessons to real world issues, and their commitment to engaging students in cross-disciplinary thinking are qualities aligned with creative teaching practices (Henriksen et al., 2016). Yet, the pervasiveness of such practices among teachers beyond our study is unclear, as these are sometimes stifled by climates of high-stakes testing. Among our own sample, we observed challenges that certain teachers faced, for instance, in handling students’ difficulties reading comics as science texts and in overcoming their own and others’ attitudes toward the place of comics and of particular science topics within formal curriculum. These observations resonate with other research on teachers’ adoption of comics in the classroom. For instance, a survey of pre-service social studies teachers found that, while they perceived value in comics as resources for their future classrooms, they also wavered in choosing to use them due to concerns over their professional credibility in the eyes of students, parents, and administrators (Clark 2013). Those teachers in our study who went on to actualize the potential they saw in the comics did so through their intentional incorporation into their lesson plans and careful alignment with standards, sometimes without support or guidance.

Therese presented a unique case, in that she was only reminded of the comics upon our request for an interview. Following her interview, she designed her own classroom-based research study into the effectiveness of the comic books. It is not possible to know the degree to which her study was prompted, albeit unintentionally, by our interest in them as researchers, and the degree to which she might have undertaken it regardless of our involvement. We can state, however, that Therese was sufficiently intrigued by the potential she saw in the comics and motivated by her commitment to equity in her teaching to undertake this significant effort.

Determining the degree to which Therese’s or any other of our participants’ efforts are atypical among most educators warrants further research with a greater number of teachers and within different educational contexts. Considering existing literature however, we might assume that more widespread adoption of similarly innovative curriculum artifacts is unlikely without system-level change in values and beliefs (Pearson and Somekh 2006; Somekh 2008). The fact that Therese needed only a brief reminder of the potential of the comics before undertaking the efforts we observed suggests that other teachers with equity priorities might be similarly enabled given access to appropriate curriculum tools.

To make more generalizable claims about the representativeness of the themes discussed here, future research might expand the number of participants observed and administer more structured interview protocols and surveys. These would enable data to be collected more systematically based on

pre-identified themes regarding what educators prioritize in their instruction, what affordances they perceive in comics, and the manners by which they enact those priorities and affordances.

Future Research on Using Comic Books to Promote Equitable Science Teaching and Learning

Whereas this study contributes to our understanding of the roles that comics play in supporting educators' equity goals, the practices we observed do not alone address all potential aspects of equitable science learning and instruction. For example, there are examples of certain of Rodriguez's (2015) guidelines that we did not observe, such as the recommendation to integrate the participation and perspectives of community leaders, family, and elders into learning activities (Table 5). Other conceptions of equity moreover encompass sociocultural dimensions that were not obviously represented in our data. For example, in outlining goals for equitable teaching within her framework of Culturally Responsive Pedagogy, Ladson-Billings (1995a, 2014) includes support for all students to achieve, no matter their background; but also for students to develop cultural competence, which means to understand and interact with people of different cultures; and to develop critical consciousness, that is, an awareness of socio-political issues relevant to one's self and community.

Because teachers' actions are constrained and capacitated by their curriculum artifacts, it is not surprising that we found little evidence of our participants using this particular comic book collection to promote the cultural, community, and sociopolitical aspects of Ladson-Billings' (1995a) and Rodriguez's (2015) frameworks. The WoV comics did not themselves directly address social inequities in their storylines. We did, however, observe their potential to be used by teachers for this purpose. For example, Audrey's discussion of *The Frozen Horror* with her students touched on the role of folklore among native communities for transmitting collective memory, in this example, of historical viral outbreaks. Without the comic, conversations about values and beliefs among non-mainstream cultures may not have otherwise arisen during a classroom lesson on viruses. While anecdotal, this example demonstrates the potential of comic books and fictional narratives in general to encourage integration of sociocultural issues into science teaching and learning and to thus advance efforts toward equitable science education (Brown 2017).

Future research might explore how comics can be designed to explicitly address issues of equity in educational contexts. For example, we might compare ways to create comic narratives that are both accurate to the science and authentic to the diversity of students' experiences. We might then explore the

impacts that characters and situations in comic stories have on different students' identification with the subject matter. Future studies might also build on research on educative curriculum materials, and on approaches to educational equity, to investigate ways to guide less experienced teachers in taking advantage of comics to promote equitable science learning.

Future research might moreover explore new approaches and extend those observed in this study, for using comics and other nontraditional materials as curriculum artifacts toward science equity goals. Toward understanding comic books as curriculum artifacts, for example, we might investigate the individual and sociocultural factors that enable some teachers to perceive and make effective use of a comic's affordances, while others to treat it simply as a traditional science text. We might further explore the impacts of teachers' approaches on students' learning. For instance, how might activities that expose students to non-traditional science texts and that value diverse literacy skills including composing original comics and using fiction as a lens for understanding science transform students' views of science? Specifically, how might these activities help to dispel common notions of science as a body of knowledge to be memorized, and rather it as a set of constructive practices that involve reflection and creative thinking? How might activities that explicitly build upon and integrate the comic's narrative and imagery, as opposed to treating them as superfluous to the science, engage students' general literacy practices and give leverage to their engagement in scientific ones? Investigating such questions about the design of comic books, teachers' approaches to using them and the impacts of these approaches on students' learning may eventually uncover best practices for promoting equitable science teaching with comic books as well as with other innovative curriculum artifacts.

BioHuman Deliverable Evaluation Study

Educator Interview

[review consent and provide written copy]

Questions

- How familiar are you with these materials? (bring materials to show interviewee)
 - Print: WoV comics, Microbe Maniacs Sticker Books, *Planet of Viruses* book,
 - Online: *Occupied!* comic, WoV apps, BioHuman/WoV website
- How did you first learn about these materials?
 - What motivated you to request them?
- Which of these materials have you used with students?

If using materials:

- How have you used these materials? (Ask for each material)

Probes:

- As part of a curricular unit? Which? Why does it fit here?
- Across the curriculum?
- How many total hours per week/weeks per year?
- In-class? Whole class or small groups or individuals?
- If not using as part of a class, how are they made available to students? Assigned reading or as an “extra”?
- What other materials/ resources do you use with these?
- What scaffolding do you use?
- Why have you chosen to use these? Motivation/engagement?
- What was student response to these materials? Probes:
 - Are certain types of students more responsive to these materials? Which? How do you know?
 - How similar to and different from other kinds of add-in resources that you use in your classroom?
 - How, if at all, have these materials influenced student motivation • engagement?
- What have been the strengths/benefits of using these materials?
- What have been limitations or issues you experienced?
- How do you plan to use them in the future?
- Have you recommended these to your colleagues would you recommend them (not just to support science, but also reading)?
- Would you be willing to allow me to observe you using these materials with students? (describe research goals, set up tentative time; provide parental notifications)
- Who else should I talk to in your building about these comics? Have others used them?

If not using materials:

- Are materials made available to students? How?
- Why did you decide not to use them? What barriers, if any, prevented you from using them?
- What would encourage/enable you to use the materials? What supports are needed?

For all:

- *Are you interested in attending a Flex session (professional development)? If so, when would be a good time? Are you interested in presenting? What would be the goals of your presentation?*

Confidentiality Question

- All formal reports will have data reported anonymously, but I may include your name in providing some specific information to the project PI for professional development follow-up. I can ensure that any or all information that you do not want associated with your name can be reported anonymously. Is there anything that you have shared with me that is sensitive and that you do not want associated with your name when shared with the project PI and staff?

Teacher Demographic/Attitudinal Survey Items

1. How often do you read comic books, manga or graphic novels?	Often	Sometimes	Once in awhile	Never
2. How often do you use comic books, manga or graphic novels with your students?	Often	Sometimes	Once in awhile	Never
3. How often do you change your science classes each year to use new resources?				
☐ I rarely use new resources in my classes ☐ I use a few new resources in my classes when I can ☐ I use new resources in some classes ☐ I use new resources in almost every class				
4. Below is a list of possible barriers to using new resources in your classes. Please rate how much they limit your ability to include new resources (circle):				
a) Lack of planning time	Very much limits my ability to add new resources	Somewhat limits my ability to add new resources	Slightly limits my ability to add new resources	Not a barrier to adding new resources
b) Limited professional development opportunities	Very much limits	Somewhat limits	Slightly limits	Not a barrier
c) Required district objectives fill available class time	Very much limits	Somewhat limits	Slightly limits	Not a barrier
d) Lack of flexibility in district curriculum	Very much limits	Somewhat limits	Slightly limits	Not a barrier
e) What other barriers limit your ability to include new resources in the science classes you teach?				
5. What, if any, professional development activities have you participated in during the last two years? Please list and briefly describe:				
6. What, if any, afterschool, summer, or other informal educational programs have you taught or facilitated in the last two years? Please list and briefly describe:				
7. How many years have you been teaching? _____ years				
8. What grades are you currently teaching?	5 th	6 th	7 th	8 th
	9 th	10 th	11 th	12 th
9. What is your sex/ gender?	Female	Male	Other	
10. What is your race/ ethnicity? (check all that apply)				
☐ Black or African American				
☐ Asian				
☐ American Indian or Alaska Native				
☐ White				
☐ Native Hawaiian or Pacific Islander				
☐ Hispanic or Latino/a				
☐ Middle Eastern				
☐ Other: <input type="text"/>				

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