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Discovering the World of Viruses: Testing the Influence of Anthropomorphic Representations on Children's Learning About COVID-19

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Having a robust understanding of viruses is critical for children to understand the COVID-19 pandemic and the protective measures recommended to promote their safety. However, viral transmission is not part of current educational standards in the United States, so children likely must learn about it through informal means, such as media and conversations with caregivers—contexts that often animate and anthropomorphize viruses. In this registered report, we developed an at-home educational intervention to teach children about viruses by creating a picture storybook about COVID-19. We tested children ages 5–8 on their understanding of viruses before and after reading the book at home with their caregivers. Critically, we manipulated which of three books children received: realistic (that detailed the microscopic processes involved in COVID-19 transmission), anthropomorphic (that depicted all the same information but using anthropomorphic language and images for COVID-19), or control (that only showed the visible aspects of illness). Bayesian analyses revealed that children learned about COVID-19 by reading the picture books with their parents at home and extended this knowledge to other viruses and that learning was substantially higher for those reading the realistic and anthropomorphic books than the control books. We also found that learning did not differ as a function of whether the book used anthropomorphic depictions or not although children reading the anthropomorphic book reported being less afraid of viruses. Altogether, these results demonstrate that carefully constructed picture books can help children learn about complex scientific topics at home.

Public Significance Statement

Children (ages 5–8) were read: (a) a book with scientifically accurate information about viruses, (b) the same book but where viruses had animal characteristics (like jumping), or (c) a control book that depicted visible aspects of the illness only. Children successfully learned about viruses by reading the picture books (particularly the realistic and anthropomorphic books) with their parents at home, indicating the effectiveness of home-based scientific learning from books.

Keywords: anthropomorphism, science education, biological reasoning, understanding of viruses, conceptual development

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The COVID-19 pandemic brought disruption to most people's lives, and children were no exception. Around the globe, children's daily activities saw significant changes with the closing of schools and the restriction of face-to-face interaction to increase children's safety. Many conversations that families had during the early stages of the pandemic focused on these disruptions to children's lives and the preventative measures available to keep family members safe (Menendez et al., 2021; Ünlütabak & Velioğlu, 2024).

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This study was preregistered. The analysis script for the power analysis, as well as all analysis scripts, and materials can be found on the Open Science Framework at https://osf.io/h4c26. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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Understanding why measures such as wearing masks and social distance help families stay safe requires that children have robust understanding of viruses and viral transmission. Yet, the importance of children's understanding of viral transmission is not reflected in the educational standards of the United States, where children are not introduced to topics related to viruses or viral transmission until high school (Next Generation Science Standards Lead States, 2013). Therefore, young children appear to be learning about viruses predominantly through informal means, such as conversations with family members (Haber et al., 2022; Menendez et al., 2021; Ünlütabak & Velioğlu, 2024) or by consuming media (Manches & Ainsworth, 2022).

Adults' descriptions and representations of viruses are not always scientifically accurate (Labotka & Gelman, 2022; Manches & Ainsworth, 2022). In particular, these informal learning opportunities tend toward animism and anthropomorphism, presenting viruses as purposeful agentic beings capable of targeting and attacking people. The use of anthropomorphism to depict and convey scientific concepts is fairly common (Brossard Stoos & Haftel, 2017; Chlebuch et al., 2023; Davies, 2010), and there are ongoing debates about its utility. Some studies show that children learn better from lessons that include anthropomorphic depictions (Brossard Stoos & Haftel, 2017; Geerdts et al., 2016; Mayer & Estrella, 2014) whereas others find that they decrease learning (Ganea et al., 2014; Larsen et al., 2018; Strouse et al., 2018). Additionally, some studies suggest that anthropomorphic depictions could reinforce children's scientific misconceptions (e.g., depicting evolutionary change as based on animals' desires; Legare et al., 2013). Given the pervasiveness of anthropomorphic information about viruses, in this study, we examined whether teaching children about viruses with anthropomorphic or realistic information influences their learning. To our knowledge, this is the first study to examine how anthropomorphic information influences children's understanding of viruses. Additionally, this is one of the few studies testing the effectiveness of an at-home educational intervention to teach children about viruses (see also Conrad et al., 2020, which focused on younger children). The primary goals of this study were to examine (a) whether children can learn about viruses through an at-home educational intervention in which they read a book with their caregiver and (b) whether (and how) anthropomorphic depictions might enhance or hinder learning.

Children's Understanding of Viruses and Illness

Prior research suggests that children have some understanding of illness and disease transmission well before high school (Bares & Gelman, 2008; Blacker & LoBue, 2016; Byrne, 2011; DeJesus et al., 2021; Jee et al., 2015; Kalish, 1996, 1998; Lockhart & Keil, 2018; Rosengren et al., 2018). By 5 years of age, children understand that germs are small and can cause illness, that certain illnesses are contagious, that contagion relates to physical distance, and that different illnesses can have different causes and consequences (DeJesus et al., 2021; Legare & Gelman, 2008; Lockhart & Keil, 2018; Nguyen & Rosengren, 2004; Raman & Gelman, 2005; but see Bares & Gelman, 2008, for evidence of children having difficulties differentiating between illnesses). However, children also often hold beliefs about illness that are not scientifically accurate. For example, many children (and adults) around the world believe that illnesses such as the common cold are caused by cold weather rather than viruses (Anggoro & Jee, 2021; Hernandez et al., 2020; Labotka & Gelman, 2022). Children also think that they are less likely to get illnesses from family members than unrelated others (Raman & Gelman, 2008). This suggests that, although children have accurate information about illnesses by or even before age 5, they also have misconceptions, some of which do not disappear with age.

Only a few studies of viral understanding have tested children since the start of the COVID-19 pandemic, and they suggest that children know more about viruses than before the pandemic (Conrad et al., 2020; DeJesus et al., 2021; Leotti et al., 2021). We are aware of only one study that has assessed children's knowledge about the COVID virus in particular (Labotka & Gelman, 2023). That work focused on 180 children between the ages of 5 and 12 years of age and found that, although even the youngest children had some scientifically accurate beliefs about viral disease, this understanding increased with age. Children as young as 5 years of age understood that viruses are too tiny to see and do not need food and that behaviors such as sneezing, coughing, and high fives can increase the risk of transmission. Children throughout the age range also understood that masks and social distancing stop the spread of COVID-19, but they rarely mentioned the biological processes that explain why. Similarly, children had difficulty understanding the processes that take place inside the body, such as viruses needing a host to replicate and that the immune system attacks viruses. Children also often did not differentiate between viruses and bacteria or between different illnesses like COVID-19 and the flu. Even the oldest children had some fundamental misunderstandings about viruses, such as thinking that a virus could enter your body through the foot, that symptoms would appear after only a brief delay, that someone with a viral disease would necessarily display symptoms, or that vaccines are curative rather than preventative.

Children appeared to use two different models when thinking about viruses: a mechanical model and an animistic/anthropomorphic model (Labotka & Gelman, 2023). Both of these models include mechanistic explanations for how viruses spread (an important feature in children's biological reasoning; Hatano & Inagaki, 1994), but both are also inaccurate. The mechanical model under relies on biology by treating viruses as inert, able to be pushed and moved around, but unable to replicate. This was also a common misunderstanding before the pandemic (Au et al., 2008; Au & Romo, 1996). For example, children that have this model think that to clean a knife that has germs in it, they should wipe off the knife with a napkin rather than submerge it in boiling water (Au et al., 2008). The anthropomorphic model over relies on biology by treating viruses like little animals. This model leads to incorrect inferences, such as reporting that viruses can grow or move by themselves. Altogether, prior work suggests that, although children have learned some accurate information about viruses, there is much about viral transmission that young children do not yet understand. Furthermore, although they sometimes focus on mechanical rather than biological mechanisms to understand what is happening inside the body, they also tend to treat viruses as biological entities similar to animals, capable of growing and moving on their own.

As noted earlier, according to science standards in the United States, children between the ages of 5 and 12 are not expected to learn about viruses or illness at school (Next Generation Science Standards Lead States, 2013); therefore, children have to learn about these concepts from other sources. Prior work has focused on how children might learn about illnesses and viruses through conversations with caregivers. Reports and recordings of child–caregiver conversations show that caregivers in the United States discuss with their children the causes of illnesses and how to prevent them, particularly when they are reading a book together in which one of the characters gets sick (Hernandez et al., 2020). However, these conversations often do not focus on the underlying biological processes (Haber et al., 2022; Menendez et al., 2021). Although caregivers often talk about germs when discussing illness, they also mention folk beliefs, such as cold weather causing illness (Hernandez et al., 2020). Additionally, adults sometimes use anthropomorphic language when talking about viruses (Labotka & Gelman, 2022; Menendez et al., 2021). This line of work shows that, although children can learn relevant scientific information from conversations or interactions with caregivers, they are also exposed to folk beliefs and nonscientific models about viruses and illness that could influence their thinking.

Prior research demonstrates that carefully constructed programs and interventions can help young children learn scientific models in a range of content areas (Brown et al., 2020; Kelemen et al., 2014; Ronfard et al., 2021), including learning about germs (Au et al., 2008). These interventions are often designed to teach 5- to 10-year-old children about complex scientific topics, such as AIDS transmission or natural selection, by focusing on underlying causal mechanisms—namely, *why* and *how* things happen (Au & Romo, 1996, 1999; Kelemen, 2019). These programs exploit children's interest in causal information (Callanan & Oakes, 1992; Shavlik et al., 2020) and rest on the assumption that providing causal mechanisms permits a deeper understanding that undergirds more accurate predictions and explanations.

Most relevant to the present study, Au et al. (2008) designed an educational program for 8- to 9-year-old children about colds and flu. Their program focused on teaching children that "germs" (undifferentiated among viruses, bacteria, and fungi) are too tiny to see; that germs can enter the body through the eyes, nose, and mouth; that they survive inside the body; and that they cause illnesses such as colds and the flu. After participating in their two-session program in school, children had a more scientifically accurate understanding of illness, including that colds and the flu are caused by germs rather than cold weather. Children also were more likely to engage in illness prevention behaviors consistent with scientific theories, such as using hand sanitizer. These interventions show that providing children with scientifically accurate mechanistic information is an effective way to promote conceptual, and possibly behavioral, change. Notably, however, this study did not instruct children on how viruses differ from nonviral "germs" (e.g., bacteria, fungi).

It is worth pointing out that all the interventions previously discussed were designed for formal learning environments (or mimicked those environments within a laboratory setting). However, as we have noted, children are curious and motivated to know about illness, and parents engage their children in conversations about it—but these tend to focus on behaviors and lifestyles rather than the biological mechanisms at play. This study introduced information about these biological processes. Recent work has begun to test the effectiveness of these mechanistic interventions in home settings with positive results (Conrad et al., 2020). Therefore, in the present study, we developed and tested an at-home intervention designed to teach 5- to 8-year-old children about viruses, viral transmission, and COVID-19.

Anthropomorphism and Its Influence in Learning

As mentioned above, even when conveying scientifically accurate information about illness, many people resort to using anthropomorphism (Davies, 2010). People can anthropomorphize information in their language (i.e., using words that conveys agency, such as "jump" or "attack," for entities that lack this trait) or their depictions (i.e., adding humanlike faces or limbs in images of entities that lack these traits). For present purposes, we will be referring to both ways of conveying anthropomorphism together as anthropomorphic representations although it is important to note that the separate effects of the two can be fruitfully disentangled (Ganea et al., 2014; Geerdts et al., 2016). Whether or not to use anthropomorphic representations when discussing or teaching complex topics is an ongoing debate studied in a variety of fields, including psychology, education, communication, and media studies. Systematic examinations of media reveal that anthropomorphic representations are common in science and educational media (Adler et al., 2022; Bonus & Mares, 2018; Chlebuch et al., 2023; Kattmann, 2008), including media related to COVID-19 (Manches & Ainsworth, 2022). However, it is unclear if using anthropomorphic language is beneficial or harmful, and arguments have been made for both directions.

On one hand, anthropomorphic representations can enhance learning. In the education literature, anthropomorphic representations are considered part of emotional design or features of lessons that influence students' emotions and, therefore, learning (Plass & Kaplan, 2016). Anthropomorphic representations in educational materials are more engaging to students (Stárková et al., 2019), which increases their motivation to learn the topic and, in turn, increases their learning. Several studies have shown this positive effect of anthropomorphic representations on student learning (Brossard Stoos & Haftel, 2017; Dorion, 2011; Geerdts et al., 2016; Mayer & Estrella, 2014; Schneider et al., 2019; Wood, 2019), and two meta-analyses have shown reliable effects of anthropomorphic depictions on learning and motivation (Brom et al., 2018; Wong & Adesope, 2021). Additionally, the effect of anthropomorphism seems to vary by age, with elementary school children benefitting more from anthropomorphic representations than older students (Schneider et al., 2019; Wong & Adesope, 2021).

On the other hand, anthropomorphic representations can hinder learning. Work in psychology and media studies shows how children are less likely to learn and generalize fantastical information to the real world (Mares & Sivakumar, 2014; Richert et al., 2009). Anthropomorphism is one feature that can make content seem more fantastical as it does not accurately represent reality, so children are less likely to generalize anthropomorphic information from books or videos (Bonus, 2019; Bonus & Mares, 2018; Ganea et al., 2014; Larsen et al., 2018; Strouse et al., 2018). It is worth noting that none of these studies were included in the meta-analyses mentioned previously. In addition, anthropomorphic media, even when embedded in otherwise scientifically accurate lessons, can lead children to adopt unscientific models that anthropomorphize different entities, such as thinking that evolution occurred because animals wanted to change (Legare et al., 2013; Waxman et al., 2014). Younger children, such as 5- and 6-year-olds, are particularly vulnerable to these negative effects (both difficulty generalizing to nonfantastical contexts and reinforcing misconceptions) than older children (Legare et al., 2013; Strouse et al., 2018). Therefore, anthropomorphic representations might reinforce misconceptions. However, how detrimental this effect is might depend on the scientific phenomenon in question. Reinforcing anthropomorphic ideas about evolution might be particularly detrimental as it supports ideas that are inaccurate as noted above. In contrast, in the context of viruses, reinforcing an anthropomorphic model could be beneficial as it might move children away from strictly mechanical models of viruses and focus them on important biological aspects of viruses, such as attaching to cells, replicating, and engaging with the immune system.

Prior research has also examined how using anthropomorphic language influences how adults think about viruses. These studies have found that using anthropomorphic language makes people think viruses are more dangerous (Byrne et al., 2009) and can lead people to adopt more preventative measures (Wan et al., 2022), suggesting that the effects of anthropomorphism in media might also be motivational and emotional.

Overall, the interdisciplinary work on the effects of anthropomorphism shows a complex picture. Anthropomorphic representations might be engaging and relatable, thus, potentially increasing children's motivation and helping them see the risks of viruses. However, anthropomorphic representations might also encourage inaccurate beliefs, such as that information provided does not extend to real viruses or that viruses are more similar to humans and other living beings than they actually are (which could reinforce misconceptions such as the idea that viruses move on their own or that they do not need a host). Although the different literatures point to opposite effects of anthropomorphism on learning, it is worth noting that both literatures suggest that younger children will be more influenced than older children by anthropomorphic representations.

The Present Study

In the present study, we were interested in how children learn about viruses, and SARS-CoV-2 specifically, from an at-home storybook intervention. We decided to implement a storybook intervention based on previous work showing that teaching children in this age range with storybooks is effective (Kelemen et al., 2014) and engaging (Frejd, 2021). How children understand living systems in the face of informal educational experiences has been identified as a core need for biology education research (Nehm, 2019). Additionally, shared book reading at home is a common practice in the United States (Ridzi et al., 2014), making it an ideal setting to deliver an intervention. Shared book reading thus provides parents and children with scientific information in a child-friendly, informal learning context. Parents are free to supplement the information in the books with stories, analogies, or connections to their child's life that might help children understand the book or to gloss over or even skip information that they do not want to discuss. We focused on 5- to 8-year-old children, as at these ages, children have room to grow in their understanding of viruses (Labotka & Gelman, 2023), and shared book reading with their caregiver is a common activity. Additionally, prior work has shown that children throughout this age range enjoy and learn from these book reading interventions, including children at the older end of the range (8-year-olds; Emmons et al., 2016; Menendez, 2022).

We designed a realistic picture story book for children that explains what viruses are and how they are different from other entities. A key challenge in communicating about viral transmission processes is that we can only see behaviors and symptoms but not the underlying causal mechanisms that give rise to these outward manifestations. Thus, for example, we might see that someone gets sick after being sneezed on, but this tells us nothing about how viruses work within the body. This contributes to a gap between behavioral recommendations ("Dos and don'ts") and a causal model, which prior research has identified as central to behavior change and appropriately generalizing to new situations (Gripshover & Markman, 2013). Therefore, in this study, the book was designed to teach children to "see the invisible" with regard to viral transmission. Specifically, we designed the book to convey seven key concepts: (1) Viruses are neither alive nor not alive because they require a host to survive and replicate. (2) Viral transmission is an invisible process where viruses are too small to see but can still make you sick. (3) Once the virus is inside the body, it uses the body's resources to replicate. (4) A person starts feeling sick after a delay, once the virus has replicated a large number of times. (5) The immune system responds to the viruses and destroys them, and that is why one gets healthy again. (6) Protective measures, such as social distancing and mask wearing, help by preventing the virus from entering the body. (7) Vaccines are different from medications in that they are preventative rather than curative. Concept 2 was tailored to match the modes of transmission of SARS-CoV-2 (and other respiratory viruses). The other concepts can be broadly applied to viruses beyond SAR-CoV-2. Please see Supplemental Materials for a table showing where these concepts are discussed in the books.

The main narrative of the book explains what happens inside the body after a COVID-19 virus enters. The book also provides causal explanations for why different preventative measures (washing hands, wearing a mask, meeting people outside, and getting vaccinated) protect a person against viruses. To test the effects of anthropomorphism, the anthropomorphic book includes anthropomorphic language and depictions. Although anthropomorphic language and depictions can have separate effects (Ganea et al., 2014; Geerdts et al., 2016), in this study, we manipulated both together in order to have a stronger and more consistent manipulation. This is also in line with commercially available books designed for children (Unlutabak et al., 2023). The anthropomorphic language characterizes the virus as an agent capable of intentional movement (e.g., "flying") and psychological activity (e.g., "hopes," "wants"). The images depict an anthropomorphized version of the virus that still looks like a virus but has an expressive face and limbs. Such anthropomorphic representations are not accurate but are common in children's educational media (Chlebuch et al., 2023) and allowed us to test the effects of anthropomorphic representations on children's understanding. We also created a control book that was similar to both of the other books in characters, drawing style, length, and information about external aspects of viral transmission (e.g., being coughed on, getting sick) and preventative measures—but importantly did not mention or depict viruses and did not convey any information about how viruses are different from other entities, what happens inside the body, or why different preventative measures are effective. This served as a baseline against which we could compare both the realistic and the anthropomorphic books.

The study comprised two sessions. In the first session, children completed a pretest to examine their understanding of viruses, followed by a session in which they read a digital version of the book with their caregiver (which was recorded). After the first session, we sent families a physical version of the book for them to read at home. Caregivers kept a log of how often they read the book with their child. The second session occurred about a month later, and children completed the same assessment as in the pretest. This allowed us to assess how much children learned from the intervention. Additionally, children were asked similar questions about a fictitious virus (the "Tacio virus") to assess their generalizations.

We hypothesized that children in the anthropomorphic and realistic conditions would have a better understanding of viruses at posttest than children in the control condition. However, given that the literature shows mixed findings on the influence of anthropomorphism on learning, we did not advance any hypotheses about whether children would learn more with the anthropomorphic or realistic book. Similarly, we hypothesized that children in the anthropomorphic and realistic conditions would transfer information presented in the book more than children in the control condition. We did not advance any hypotheses about differences between the anthropomorphic and realistic conditions on transfer because transfer depends on how much children learn; although there is work showing a decrease in transfer when learning with anthropomorphic representations (Strouse et al., 2018), this could be offset by increases in learning. Given children's curiosity about causal information, we hypothesized that they would read and enjoy both experimental books more than the control as shown by the reading log. Additionally, given the pervasiveness of anthropomorphism in children's media, we hypothesized that children would read and enjoy the anthropomorphic book more than the realistic book. Additionally, given prior research with adults (Byrne et al., 2009; Wan et al., 2022), we hypothesized that children would be more scared about viruses in the anthropomorphic condition than the realistic condition.

We performed all data analyses using a Bayesian framework, which allowed us to interpret null effects and explore where the bulk of the distribution of effects lies.

Method

Participants

We conducted a Bayesian power analysis by simulating data with different sample sizes, fitting a Bayesian regression to the simulated data, and examining whether the 95% highest density interval (i.e., an interval showing the most credible values for the parameter) did not include 0 (indicating that there is evidence for an effect of a variable). We then repeated this process for a total of 1,000 simulations. The analysis script for the power analysis can be found here on the Open Science Framework at https://osf.io/h4c26. For the effect of anthropomorphism, we used the effect size for anthropomorphic depictions from Wong and Adesope (2021; this is the most recent and comprehensive meta-analysis on this topic) of $g = 0.55$. Even though the meta-analysis found that the effect was larger for younger children, we used the effect found for participants of all ages (kindergarten to college students) to be more conservative with our estimates. It is worth noting that this effect size is closely aligned with the comparison of the anthropomorphic and realistic books, but the effect was smaller than the anticipated comparisons with the control. We made this decision because prior work comparing interventions that provide mechanistic information to control interventions have found effect sizes that are larger than the 0.55 used in the power analysis. We also included an effect of age of $b = 0.03$ from our prior work on children's knowledge about viruses (Labotka & Gelman, 2023). The simulations suggest that 70 children per condition (210 total) should be sufficient to detect the hypothesized effect of anthropomorphism. We increased this number to 72 per condition (216 total) to allow for even age distributions within each condition. When anthropomorphism was the only variable in the model, 88.9% of the simulated data sets had 95% highest density intervals that did not include 0, and this went up to 100% when we included age in the model.

We preregistered recruiting at least 216 children ages 5–8 to participate in both sessions of the study. We preregistered excluding participants for analyses for the following reasons: not answering at least half of the questions, having severe technical difficulties, or receiving substantial parental interference. Given the possibility of attrition between the first and second sessions, we preregistered over sampling by 10%, meaning that the preregistered final sample size would be between 216 and 238 participants. Our final sample was 235 5- to 8-year-old children for Session 1 (109 girls, 126 boys; $M_{\text{age}} = 7.19$, $SD_{\text{age}} = 1.07$) and 220 children for Session 2 (101 girls, 119 boys; $M_{\text{age}} = 7.17$, $SD_{\text{age}} = 1.09$). An additional two children were run but excluded from the study due to parental or sibling interference. Additionally, the second sessions of three children were excluded due to parental interference ($n = 1$) or experimenter error ($n = 2$). Experimenter error was not a preregistered exclusion criterion but was necessary given that on one occasion the experimenter ran the child through the first session protocol for the second session. Data were collected from July 2023 to March 2024. As preregistered, the data from participants who completed only the first session were retained and analyzed in models focusing uniquely on the pretest.

We aimed to recruit a diverse sample of U.S. families, including White families from rural areas and Black and Latinx families from urban areas and families living in or near a university community. According to parental report at Session 1, 156 children were White, 25 Asian or Asian American, 18 Black or African American, 10 Hispanic or Latinx/e, one Arab or Middle Eastern, 24 bi- or multiracial/ethnic, and one who did not want to answer. Two hundred six participants lived in urban counties (counties with rural–urban continuum codes between 1 and 3 based on zip code data from the department of agriculture), 23 lived in rural counties (counties with codes between 4 and 9), and six participants were without available data. One parent reported that their highest level of education was less than high school, five reported high school or general education diploma, 13 completed some college, 11 had an associate's degree, 91 had a bachelor's degree, 82 had a master's degree, 28 had professional or doctoral degrees, one reported other higher level of education ("ARM certification"), and three did not report their highest level of education. In terms of household income, five parents reported having incomes of less than $15,000 a year, four had incomes between $15,000 and $25,000, 13 had incomes between $25,000 and $50,000, 30 had incomes between $50,000 and $75,000, 46 had incomes between $75,000 and $100,000, 73 had incomes between $100,000 and $150,000, 59 had incomes above $150,000, and five did not report income. Participating families were compensated with $40 in gift cards for their participation in the study: $10 after the first session and $30 after the second session. The study was conducted online using the video conferencing platform Zoom.

Design

The study used a pretest–intervention–posttest design with two online sessions. The first session included the pretest and families' first reading of the intervention book. The second session included the posttest and transfer test. There were at least 3 weeks in between the sessions, and we aimed for approximately 1 month between sessions for all participants (M = 38.32 days, SD = 13.96 days, range = 24 days, 140 days). Within each 2-year age group (5–6 years, 7–8 years), participants were randomly assigned to one of three book conditions (control, anthropomorphic, realistic), thus, ensuring that the proportion of participants in each condition was relatively even across age groups.

Measures and Materials

Knowledge Tests

At both pretest and posttest, we assessed children's knowledge about COVID-19. The majority of the questions were adapted from Labotka and Gelman (2023) to assess a variety of beliefs about viruses for which children were not at ceiling and to include a range of difficulty so that we could still assess prior knowledge in the youngest children. In particular, our assessment tapped into children's knowledge about features of viruses, transmission risks, asymptomatic carriers, delays in symptom onset, and protective measures. Table 1 presents the exact wording of the questions. We refer to the questions assessing information that appeared in the anthropomorphic and realistic books as "learning questions." We refer to questions assessing information that did not appear in these books as "COVID-19 transfer questions." Table 1 shows which questions were learning or COVID-19 transfer, under the column "question type."

After the posttest, we included a virus transfer test, in which children heard a subset of the pretest/posttest questions, but asked with regard to a fictitious virus and viral disease, the Tacio virus (which causes the Tacioitis disease). This served as a measure of participants' generalization. We selected questions that were discussed in the book in the context of COVID-19 (rather than in the context of generally discussing viruses or protective measures) or that assessed whether children anthropomorphized viruses by attributing to them wants or desires. Table 1 shows which questions were included in the Tacio virus transfer test.

Deviations From Preregistered Protocol

There were four deviations from the preregistered protocol described above. Following two questions about asymptomatic carriers and the question about whether viruses are alive, participants were asked to explain their answers. Additionally, we included a question about whether the Tacio virus was alive. These questions were part of previous protocol (Labotka & Gelman, 2023) and were mistakenly not removed from the current protocol. Given that they were not part of the preregistered protocol, they were not analyzed, and we do not discuss them further.

Emotional Response

To examine if anthropomorphism (or information regarding viruses in the body, in either of the noncontrol books) influenced children's emotions toward viruses, the posttest asked, "How do you feel about viruses? Not scared, A little scared, Very scared."

Book

We designed three picture storybooks for this study (see Supplemental Materials for the full text of each book), and all books were checked by a virologist (MD, PhD) for accuracy. The realistic book starts by discussing general properties of viruses, including how viruses are different from animals and rocks, and how viruses have different functions inside and outside the body. Then, the book introduces a child, Sam (who was gender-matched to the participants' gender) who is going to the store with their sister. While at the store, a man coughs on the child and spreads COVID-19 viruses (SARS-CoV-2). The book then details how the virus spreads around a room and how the virus enters the body. Then, the book describes how the virus is transported to the lungs, where it attaches to the cells in the lungs to create new copies of the virus. The book discusses that this process takes time to unfold and that is why there is a delay in symptom onset. The book then shows how our immune system destroys the viruses, helping us feel better. Finally, the book presents four preventative measures (i.e., mask wearing, vaccination, meeting people outside, and hand washing) and explains why each is effective at protecting us from viruses.

The anthropomorphic book presents all the same information as the realistic book but uses anthropomorphic representations. Anthropomorphic language conveys agentic movement, such as the virus stealing energy, flying out of the body, grabbing onto parts, and moving around, as well as psychological properties, such as the virus wanting to make people sick and hoping to go into other people. Anthropomorphic images depict the virus as having a humanlike face, facial expressions, and limbs. Figure 1 shows an example of the same book page in the anthropomorphic and realistic conditions.

The control book shows the same child and their sister on their trip to the store. The book goes into more detail about what they do at the store, including the sections that they visit, what they want to buy, and what they eat. As in the other versions, the book also shows the man coughing on the child. All the observable events are the same (e.g., the child getting sick after a few days and then getting better). However, no explanations are provided for why these events happen, nor is any information included about unobservable phenomena such as viruses entering the body or an immune response. The control book presents the same four preventative measures and mentions that they are effective ways to stay safe but does not explain why they are effective.

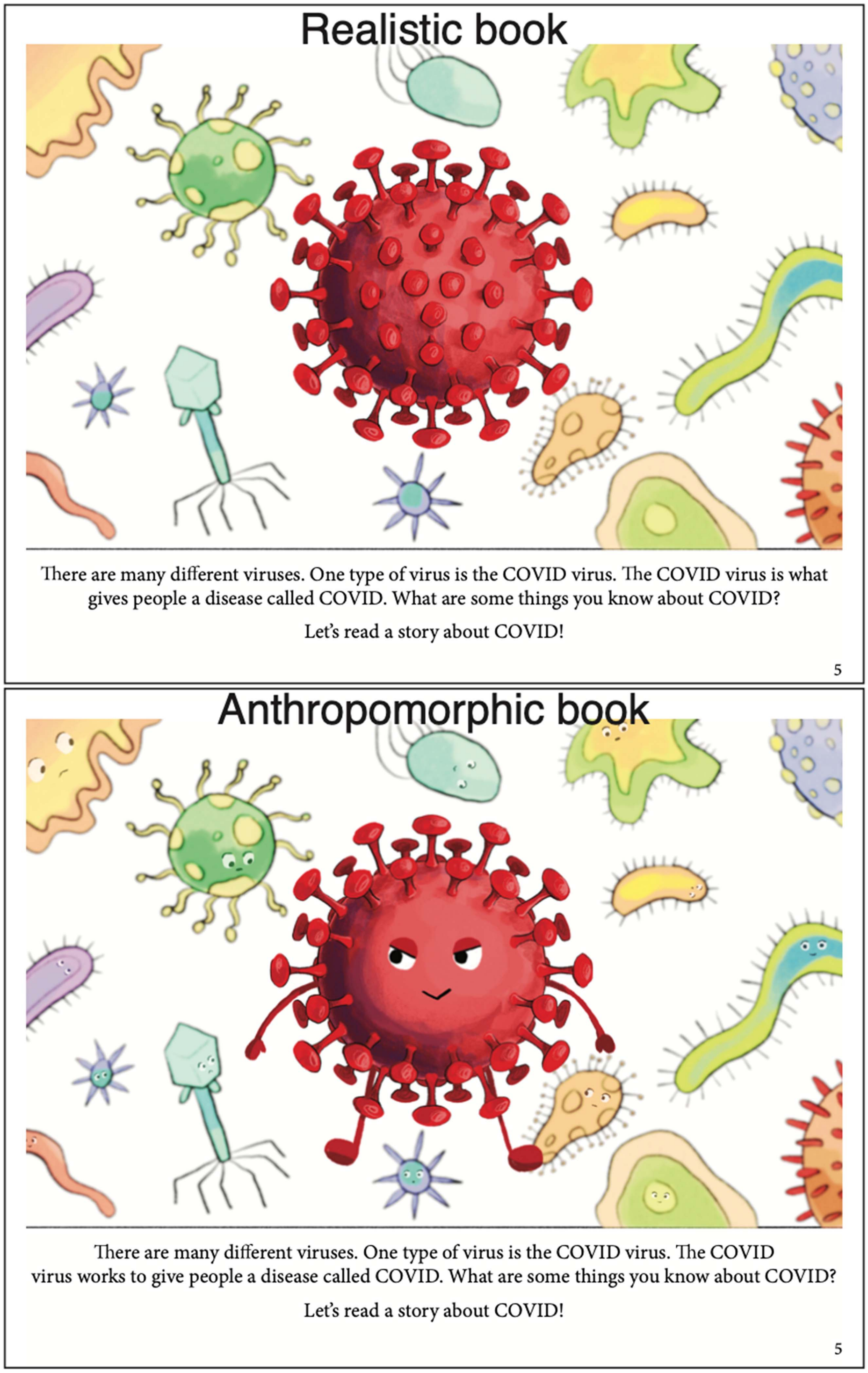
All three books have the same number of pages. The same events happen in the same pages in all the books (with the exception of the control book, which shows the child getting sick two pages later than the other books to keep the narrative consistent). All books have four engagement questions to promote child–caregiver conversations (e.g., "When do you think Sam will start to feel sick?"), and these questions are the same for the anthropomorphic and realistic books. All the questions appear in the same position in the respective books, with the exception of one question in the control book that appears two pages later to preserve the narrative. All books and a document

Table 1
Pretest and Posttest Questions About COVID-19

Topic	Pretest and posttest question	Scientifically accurate answer	Question type	Included in Tacio Virus Transfer Test
Transmission risks	Think about a person who has COVID. Could they give someone else COVID by coughing on them?[a]	Yes	Learning	Included
	Think about a person who has COVID. Could they give someone else COVID by singing together?[a]	Yes	COVID-19 transfer	Not included
	Think about a person who has COVID. Could they give someone else COVID by blowing out birthday candles?[a]	Yes	COVID-19 transfer	Not included
	Think about a person who has COVID. Could they give someone else COVID when standing on opposite sides of a closed glass door?[a]	No	COVID-19 transfer	Not included
	These two people are wearing masks and they are giving a high-five. These two people are not wearing masks and they are not touching. Which two people are SAFER from COVID?	Not wearing mask and touching	COVID-19 transfer	Not included
	Why?	COVID-19 transmit through air and droplet[b]	COVID-19 transfer	Not included
Asymptomatic disease	This lady feels great. She's not coughing or sneezing. She does not have a fever or headache. Could she have COVID?[a]	Yes	Learning	Included
	Could she give someone else COVID?[a]	Yes	COVID-19 transfer	Not included
Causal mechanisms/protective measures	Why do you think wearing a mask helps protect you against COVID?[a]	Blocks virus[b]	Learning	Not included
	Why do you think washing your hands helps protect you against COVID?[a]	Kills/destroys virus[b]	Learning	Not included
	Why do you think meeting someone outside instead of inside helps protect you against COVID?	Virus is harmed or dissipates[b]	Learning	Not included
	Why do you think getting the COVID vaccine helps protect you against COVID?	Prepares body to destroy/fight virus[b]	Learning	Not included
	This kid is taking some medicine for an ear infection. Will the same medicine help him get better from COVID?	No	COVID-19 transfer	Not included
Delayed onset	This man had COVID and coughed on this woman. When would she start to feel sick: the same day, or later—on a different day?[a]	Later	Learning	Included
	Why did it take a few days for her to feel sick after the viruses got inside her body?[a]	Viral replication[b]	Learning	Included
Virus features	Can a COVID virus grow bigger in size?[a]	No	COVID-19 transfer	Not included
	Can a COVID virus move by itself?[a]	No	COVID-19 transfer	Included
	Does a COVID virus need food?[a]	No	COVID-19 transfer	Not included
	Can a COVID virus breathe?	No	COVID-19 transfer	Not included
	Can a COVID virus feel pain?	No	COVID-19 transfer	Included
	Can a COVID virus try to get someone sick?	No	COVID-19 transfer	Included
	Can a COVID virus make copies of itself?	Yes	Learning	Included
	Does a COVID virus use energy?	Yes	Learning	Included
	Is there anything different for a COVID virus when it's inside a person's body than when it's outside a person's body?	Yes	Learning	Included
	If a COVID virus gets inside your body, does it know anything about you?	No	COVID-19 transfer	Not included
	Is a COVID virus alive or not alive?[a]		Not applicable	Not included
	In real life, how big is a COVID germ?[a]	Too tiny to see	Learning	Not included

[a] Questions were from prior work by Labotka and Gelman (2023). [b] Responses represent open-ended questions. Therefore, the text in the "Scientifically accurate answer" column is just one sample response. Responses to these questions were coded for accuracy. The question asking if a COVID-19 virus is alive did not include a scientifically accurate answer because there is no scientific consensus (Villarreal, 2004). Questions marked as "Learning" were explicitly discussed in the book. Questions marked as "COVID-19 transfer" were not explicitly discussed in the book and, thus, required children to generalize.

Figure 1
Sample Book Page in the Realistic (Top Panel) and Anthropomorphic Conditions (Bottom Panel)



Note. The labels "realistic book" and "anthropomorphic book" were not presented to participants. Adapted from *Testing the Influence of Anthropomorphic Representations on Children's Learning About COVID* (p. 5), by D. Menendez and S. A. Gelman, 2024 (https://osf.io/h4c26/). CC BY-NC. See the online article for the color version of this figure.

detailing the text differences between the anthropomorphic and realistic books can be found here on the Open Science Framework at https://osf.io/h4c26.

Reading Log

Inside the physical version of the book, we included a log where caregivers could record how many times their child read the book in between the two sessions, either by themselves or with their caregiver. The log also included a rating scale for caregivers to fill out rating about how much their child enjoyed reading the book and to state whether the child or caregiver (or both) initiated the book reading. We included a prestamped envelope for caregivers to send the log back after their second session. They also had the option to take a picture of the log and send it to us over email. Additionally, we asked caregivers to show the log on camera during the second session to have a picture in case families forgot to mail it back or the envelope got lost in the mail.

Manipulation Check

At the end of the second session, we asked children, "Which of these pictures did you see in the book you read with your family?" and showed them equivalent images from the realistic, anthropomorphic, and control books. Each child received two of these questions. Additionally, for children in the anthropomorphic and realistic conditions, we asked them which sentence they saw in the book they read with their family and presented two pairs of sentences (each pair containing one sentence from each book that reflected the differences in wording by condition; e.g., "Now your body is ready if a COVID virus gets inside" vs. "Now your body is eager to fight a COVID virus if it gets inside").

Procedure

Caregivers completed an online consent form and demographic form before the start of the first session. Children were tested individually by a trained experimenter using the Zoom video conferencing platform. In the first session, children first completed the pretest assessing their understanding of viruses, during which the experimenter shared their screen to show children the images accompanying each question. After the child completed the pretest, a caregiver was asked to join the child if they were not already present during the pretest. The experimenter sent them a link to an ebook version of the book that matched their condition assignment and the gender of their child. Caregivers and children were asked to read the book in a way that felt natural to them while being sure to say something about every page in the book. The experimenter turned their own audio and video off (but families were still video and audio recorded), and families had as much time as they needed to read the book. We included this shared book reading activity as part of the first session to ensure that all participants read the book at least once before the posttest. Transcripts of these recordings will be available for further analysis upon request, but we do not analyze them for the present report.

After the first session, we sent a physical version of the book to the family, and families were asked to read the book with their child at least four times over the next few weeks. However, families were not excluded if they read the book fewer than four times. The second session took place at least 3 weeks after the first session. This way, families had enough time to read the books at home. During the second session, children completed the posttest, transfer test, emotional response measure, and manipulation check. Then, the experimenter asked the caregiver to show their reading log on camera (which was screenshotted) and instructed them on how to mail it back. Families kept the book, as thanks for their participation, in addition to the gift cards mentioned previously. Additionally, at the end of the study, we debriefed all families by telling them that viruses cannot move on their own and do not have faces and sent an ebook version of the realistic book to all families. Both sessions were video and audio recorded.

Transparency and Openness

This is a registered report; thus, the hypothesis, method, and analysis plan were preregistered. All materials, data, and analysis scripts can be found on the Open Science Framework at https://osf.io/h4c26/.

Results

Data Analyses Plan

Given the inconsistent findings in the literature regarding the effects of anthropomorphism on children's learning, we conducted all analyses under a Bayesian framework (see Kruschke & Liddell, 2018, for an overview on Bayesian data analysis). Bayesian data analysis has the advantage of allowing us to examine the distribution of credible effects rather than looking at one point estimate. This distribution of effects is summarized by the 95% highest density interval, which includes most of the posterior distribution and includes the most likely values for the size of the effect. We report on effects where more than 90% of the posterior distribution is in the same direction as the beta. We conducted the analyses in R (R Core Team, 2023) using the RStan package (Stan Development Team, 2023) and brms package (Bürkner, 2017).

To conduct Bayesian analyses, one needs to set prior distributions for each predictor variable. For all predictors in all models, we set skeptical priors (i.e., normal distributions with a mean of 0 and a standard deviation of 0.5). These bias the models toward 0 (i.e., the predictor has no effect) and values close to it. For multilevel models, we used a half Student's t distribution with a mean of 0 and a standard deviation of 2.5 as our prior for the standard deviation for all the random effects (default priors in brms). This is a weakly informative prior that allows for only positive numbers (as standard deviations can only be positive). For the correlation matrix of the random effects, we used lkj(1) as our prior (also the default in brms), which places equal probability on all possible correlation matrices (this prior is uniform over the entire correlation matrix; individual correlation values are biased toward 0, with all values between −1 and 1 being possible).

For each regression, we ran four Markov chains, with 5,000 iterations each, with 1,000 warm-up draws. We started with a baseline model and then fit increasingly more complex models. We only interpret the results from the best fitting model. To determine the best fitting models and avoid overfitting, we performed leave-one-out cross-validation using the loo package (Vehtari et al., 2023).

During leave-one-out cross-validation, the model is trained on all the data except one observation, which is used to test the model's predictions. This process is repeated until every observation has been used to test the model, and the model fit is assessed by the average prediction error. The results of the leave-one-out cross-validation can be used to compare different models by comparing their expected log predictive density (elpd). The model with the largest elpd is considered the best fitting model. In Table 2, we detail the models, we fit for each outcome variable and the results of the model comparison.

For analytical purposes, when we refer to pretest knowledge, we mean the composite score of how many questions children answered correctly at pretest. When we refer to posttest knowledge, we mean the composite score of how many COVID-19 questions children answered correctly at posttest. When we refer to learning, we focus on the subset of questions (at both pretest and posttest) that were addressed in the book. When we refer to COVID-19 transfer, we focus on the subset of COVID-19 questions (at both pretest and posttest) that were not addressed in the book. When we refer to Tacio virus transfer, we mean the composite score of how many questions about the Tacio virus children answered correctly at posttest. In all analyses, we used two orthogonal contrasts to analyze the effects of book condition. The first contrast compared the two experimental books to the control book (Contrast 1: control = −0.66, anthropomorphic = 0.33, realistic = 0.33), and the second one compared the anthropomorphic and realistic books to one another (Contrast 2: control = 0, anthropomorphic = −0.5, realistic = 0.5). For all analyses with the number of times families read the book at home as a predictor, we used multiple imputation using the mice package to address the missing data.

Preregistered Analyses

Pretest Knowledge

To replicate Labotka and Gelman (2023), we examined children's knowledge of viruses at pretest. Consistent with prior work, children at all ages had some knowledge of viruses, and there was evidence that this was different from zero, $b = 2.98$ (0.80, 5.20). Also consistent with prior work, this understanding increased with age, $b = 1.29$ (0.99, 1.59). An exploratory analysis comparing the conditions at pretest can be seen in the Supplemental Materials; no differences were obtained.

Posttest Knowledge

We examined children's performance at posttest and whether condition predicted their performance. We controlled for pretest performance rather than examine change from pretest because analyses that control for pretest performance have greater power for experimental studies than analyses examining change from pretest (Van Breukelen, 2006). We found that the best fitting model included interactions between conditions and children's age. We found evidence for an effect of age, such that older children had higher scores than younger children, $b = 0.37$ (0.03, 0.71). There was no evidence for an effect of the first contrast (comparing the control against the anthropomorphic and realistic conditions), $b = 0.05$ (−0.91, 1.00). However, as hypothesized, there was an interaction between children's age and the first contrast, $b = 0.44$ (0.28, 0.60). As can be seen in Figure 2, children who read the anthropomorphic ($M = 16.7$, $SD = 3.25$) or realistic books ($M = 16.7$, $SD = 3.61$) had higher scores than children

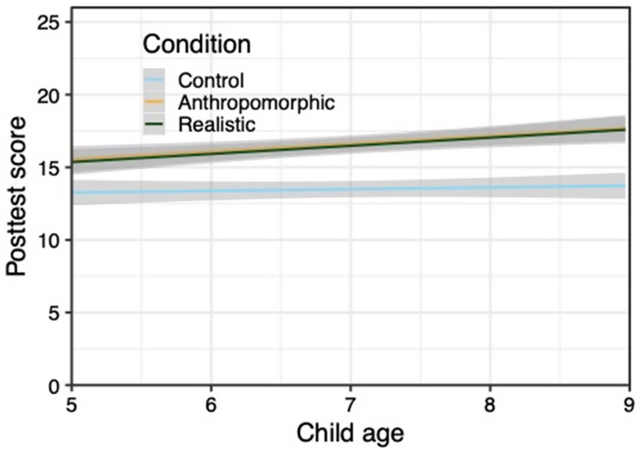
Table 2
Description of Models Fit for Each Outcome Variable With the Model Comparison Indices

Outcome	Predictor	Δelpd	*SE*
Pretest knowledge	**Baseline: Intercept + age**	NA	NA
Posttest knowledge	Baseline: Intercept + age + book condition + pretest knowledge	−3.9	3.0
	Number of times they read the book at home	−4.8	3.0
	Book Condition × Age	**0.0**	**0.0**
	Book Condition × Pretest Knowledge	−1.5	0.3
Learning	Baseline: Intercept + age + book condition + test time	−28.5	7.4
	Book Condition × Test Time	**0.0**	**0.0**
COVID-19 transfer	**Baseline: Intercept + age + book condition + test time**	**0.0**	**0.0**
	Book Condition × Test Time	−0.8	1.5
Tacio virus transfer	**Baseline: Intercept + age + book condition + posttest knowledge**	**0.0**	**0.0**
	Number of times they read the book at home	−0.8	0.5
	Book Condition × Age	−1.2	0.7
	Book Condition × Posttest Knowledge	−1.1	2.0
Reading log	**Baseline: Intercept + age + book condition + pretest knowledge**	**0.0**	**0.0**
	Book Condition × Age	**0.0**	**0.4**
	Book Condition × Pretest Knowledge	−1.4	0.8
Mean enjoyment	**Baseline: Intercept + age + book condition + pretest knowledge**	**0.0**	**0.0**
	Book Condition × Age	-0.8	0.4
	Book Condition × Pretest Knowledge	−1.7	1.2
Emotional reaction	**Baseline: Intercept + age + book condition + pretest knowledge**	**0.0**	**0.0**
	Number of times they read the book at home	−1.2	0.2
	Book Condition × Age	−1.7	0.6
	Book Condition × Pretest Knowledge	−2.7	1.7

Note. The model for pretest knowledge does not have any model comparison indices because there is only one model; therefore, there is no additional model to compare. Models in bold are the best fitting model for a given analysis. *SE* = standard error; NA = not applicable.

Figure 2

Children's Performance at Posttest (y-Axis) as Function of Child Age (x-Axis) and Book Condition (Different Colored Lines)



Note. Posttest scores ranged from 0 to 26. Regression lines control for pretest scores. Error bands show the 95% highest density interval. See the online article for the color version of this figure.

who read the control book (*M* = 13.5, *SD* = 2.73), and this difference became wider with age. The interaction shows that older children benefitted more from the anthropomorphic and realistic books than younger children. However, there was no difference between children who read anthropomorphic or realistic books, *b* = −0.15 (−1.10, 0.81), nor an interaction between them and age, *b* = 0.00 (−0.17, 0.17). We also found that children who had higher pretest scores also scored higher at posttest, *b* = 0.57 (0.45, 0.70). There was no evidence that the number of times families read the books at home influenced posttest scores, *b* = 0.05 (−0.24, 0.33).

To test whether there was an increase in children's knowledge from pretest to posttest, we also examined whether children scored higher on the posttest than the pretest and whether this varied by condition. For this analysis, we separated the posttest into learning questions and COVID-19 transfer questions. This analysis of change from pretest narrows in on whether the potential increases are due to differential learning or transfer.

Learning. The best fitting model included an interaction between condition and test time. As a reminder, this analysis involved looking at whether children answered each question correctly or not; thus, we report the proportion of questions answered correctly (rather than the number of correct responses as in previous analyses). Again, we found an effect of child age, *OR* = 1.25, *b* = 0.22 (0.16, 0.29). We also found that children were more likely to answer the learning questions correctly in the posttest (*M* = 0.60, *SD* = 0.49) than in the pretest (*M* = 0.40, *SD* = 0.49), *OR* = 2.34, *b* = 0.85 (0.74, 0.97), showing that they learned from the book. As hypothesized, this was moderated by an interaction with the first contrast, *OR* = 2.46, *b* = 0.90 (0.66, 1.14). Across pretest and posttest, children who read the anthropomorphic (*M* = 0.53, *SD* = 0.50) or realistic book (*M* = 0.55, *SD* = 0.50) learned more than those who read the control book (*M* = 0.41, *SD* = 0.49). There was no evidence for an interaction between the second contrast (anthropomorphic vs. realistic) and test time, *OR* = 0.94, *b* = −0.07 (−0.33, 0.20).

COVID-19 Transfer. The best fitting model did not include an interaction between condition and test time. Again, we found an effect of child age, *OR* = 1.26, *b* = 0.23 (0.17, 0.29). We also found that children were slightly more likely to answer the COVID-19 transfer questions correctly in the posttest (*M* = 0.61, *SD* = 0.49) than in the pretest (*M* = 0.54, *SD* = 0.50), *OR* = 1.32, *b* = 0.28 (0.18, 0.38). Contrary to our hypothesis, there was no effect of the first contrast, *OR* = 1.05, *b* = 0.05 (−0.08, 0.18), or the second contrast, *OR* = 1.02, *b* = 0.02 (−0.13, 0.17). Overall, this shows that children were able to transfer what they learned from the book but that the type of book did not seem to influence this.

Tacio Transfer

We also examined children's responses to a novel virus (called Tacio virus). The best fitting model included age, condition, and posttest scores. As hypothesized, we found that children who read the anthropomorphic (*M* = 6.11, *SD* = 1.81) or realistic book (*M* = 6.36, *SD* = 1.93) answered more questions correctly than children who read the control book (*M* = 4.97, *SD* = 1.40), *b* = 0.40 (−0.05, 0.84), probability of direction = 95.98%. There was no evidence for a difference between the realistic and the anthropomorphic book, *b* = 0.20 (−0.25, 0.65), or an effect of age, *b* = −0.03 (−0.23, 0.18). There was an effect of posttest, such that those who scored higher on the COVID-19 posttest also scored higher on the Tacio transfer test, *b* = 0.24 (0.17, 0.31).

Reading Log

For the analyses of the reading log, we fit two regressions, one analyzing the number of times the child read the book and another analyzing the average enjoyment rating.

Number of Times They Read the Book. Overall, families read the book at home 4.50 times (*SD* = 1.14). The baseline model and the model that included the interaction between condition and age both fit the data equally well. Here, we interpret the model with the age interaction; however, there was little evidence for any of the predictors having an effect: age: *b* = −0.03 (−0.22, 0.16), first contrast: *b* = 0.44 (−0.47, 1.36), second contrast: *b* = −0.20 (−1.13, 0.73), pretest score: *b* = 0.00 (−0.07, 0.07), age by first contrast: *b* = −0.05 (−0.18, 0.09), or age by second contrast: *b* = 0.00 (−0.14, 0.14). This is against our hypothesis that children would read the anthropomorphic or realistic books more than the control book.

Average Enjoyment Rating. Overall, families moderately enjoyed reading the book (*M* = 3.62 out of 5, *SD* = 0.98), with 82% providing at least a 3 on the 1–5 scale and over half rating their enjoyment as a 4 or 5. The best fitting model included age, condition, and pretest score. There was no evidence for an effect of age, *b* = −0.11 (−0.27, 0.04), condition, first contrast, *b* = 0.11 (−0.20, 0.41), second contrast, *b* = 0.07 (−0.25, 0.80), nor an effect of pretest score, *b* = −0.02 (−0.07, 0.03). This is against our hypothesis that children would enjoy the anthropomorphic (*M* = 3.63, *SD* = 0.99) and realistic books (*M* = 3.72, *SD* = 0.97) more than the control book (*M* = 3.52, *SD* = 0.97).

Emotional Reaction

For the analysis of emotional reaction, we fit one regression examining how scary children thought viruses are. The best fitting model included age, book condition, and pretest score. We found that older children found viruses less scary than did younger children, $b = -0.08$ (−0.18, 0.01), probability of direction 95.51%. We found little evidence for an effect of the first contrast, $b = -0.05$ (−0.23, 0.14), but we found evidence for an effect of the second contrast, $b = 0.30$ (0.08, 0.51). Contrary to our hypothesis and prior research with adults, children who read the realistic book ($M = 1.86$, $SD = 0.69$) were more scared of viruses than children who read the anthropomorphic book ($M = 1.57$, $SD = 0.65$). There was little evidence for an effect of pretest score, $b = -0.03$ (−0.06, 0.01).

Manipulation Check

For analyses of the manipulation check, we examined the proportion of children who selected the image and text from the book they were assigned to (with separate analyses for the image and text) and compared this to chance (again separately for the image and text). The Bayesian models showed that across conditions children correctly selected the images that were shown in their assigned book (control: $b = 91.76\%$ [87.54%, 94.83%], anthropomorphic: $b = 79.58\%$ [72.91%, 85.32%], and realistic: $b = 79.41\%$ [73.11%, 85.57%]; chance = 33%). It is worth noting that there was an effect of condition, such that children who read the control book were better at recognizing the images from their book than children who read the anthropomorphic, $b = -1.07$ (−1.62, −0.52), or the realistic book, $b = -1.08$ (−1.63, −0.54). There was no evidence of a difference between children who read the anthropomorphic or realistic book, $b = -0.18$ (−0.66, 0.30). When children who read the anthropomorphic book answered the manipulation check incorrectly, they more often selected the realistic image (20 mistakes; 20 children for the first question and zero children for the second question) than the control image (16 mistakes; eight children for the first question and eight children for the second question). When children who read the realistic book answered the manipulation check incorrectly, they more often selected the control image (26 mistakes; 13 children for the first question and 13 children for the second question) than the anthropomorphic image (10 mistakes; nine children for the first question and one child for the second question). Turning to the identification of sentences, children in the anthropomorphic and realistic conditions also typically selected the sentences assigned in their assigned book (anthropomorphic: $b = 87.44\%$ [78.24%, 94.16%], and realistic: $b = 88.59\%$ [80.06%, 94.63%]; chance = 50%). There was no difference between the two conditions on whether children correctly identified the sentences in their book, $b = -0.12$ (−0.77, 0.52). Overall, this shows that children in the study remembered which book they were assigned.

Exploratory Non-Pre-Registered Analyses

Change by Item

One important aspect to note is that our assessment of children's knowledge did not have strong internal consistency (Cronbach's α at pretest = .50 and at posttest = .51). Therefore, in addition to the preregistered analyses described above, we also conducted exploratory analyses were we examined differences at the item level (see Supplemental Materials for details). Given the exploratory nature of these analyses and the high number of comparisons, the results should be interpreted with caution. For each item, we tested whether there was a difference between the proportion of children in each condition that answered the question correctly at pretest and posttest. We found that the proportion differed in 33 cases, all showing improvements in children's understanding (there was little evidence for decreases in children's understanding for any question). Three items showed increases in all conditions (symptom delay, whether viruses move by themselves, and the size of viruses). This shows that children in the control condition did learn from the book reading, suggesting that the previously mentioned differences from the control condition are not due to inattention from the children in the control condition. Nine items showed increases in the anthropomorphic and realistic conditions (why masks help, why washing hands help, why meeting people outside help, why vaccines help, why is there a delay in symptoms, whether viruses grow, whether viruses feel pain, whether viruses make copies of themselves, and whether viruses use energy). We should note that these included all of the open-ended questions, which required children to explain their understanding, and many of the questions about the biological processes of viruses. Two items showed improvements only in the anthropomorphic condition (whether viruses need food, can you give COVID-19 by singing together), and one item showed improvement only in the realistic condition (can you give COVID-19 by standing on opposite sides of a closed- door). None of the items showed increases only in the control condition.

Anthropomorphism

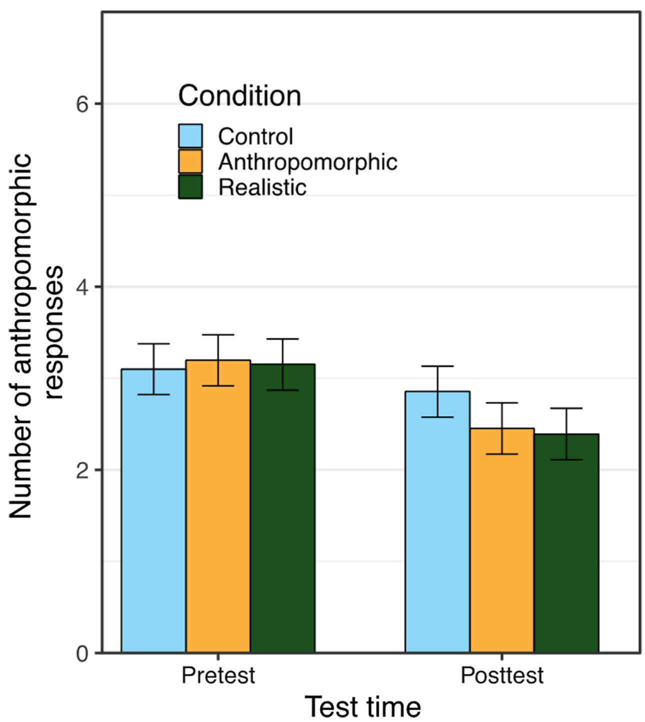
We also examined children's responses to questions that anthropomorphized the virus, specifically whether viruses can grow, move by themselves, need food, can breathe, feel pain, can try to get you sick, and are alive. For all of these questions, a "yes" answer is scientifically incorrect and indicates a tendency to anthropomorphize. We used this as our dependent variable. The results of the model comparison can be seen in the Supplemental Materials. The best fitting model included age, condition, test time, and interactions between condition and age and between condition and test time. We found that children were less likely to anthropomorphize at posttest compared to at pretest, $b = -0.57$ (−0.75, −0.40). This was moderated by an interaction with the first contrast, $b = -0.56$ (−0.93, −0.20). As can be seen in Figure 3, at pretest, the levels of anthropomorphism were similar in all conditions. But at posttest, children in the anthropomorphic and realistic condition anthropomorphized *less* at posttest than children in the control condition. There was no effect of the second contrast, $b = 0.30$ (−0.59, 1.21), nor an interaction between the second contrast and test time, $b = -0.01$ (−0.40, −0.39), suggesting that there is little or no difference between the realistic and anthropomorphic conditions. There was a trend suggesting that older children anthropomorphized less than younger children, $b = -0.10$ (−0.23, 0.03), probability of direction = 93.73%, but this was not reliably different from 0. There was also little evidence for an interaction between age and the first, $b = -0.07$ (−0.20, 0.06), or the second contrast, $b = -0.05$ (−0.18, 0.08).

Initiating Reading

Descriptively, families read the books 911 times total. Of these readings, 270 were initiated by children, 399 were initiated by

Figure 3

Children's Number of Anthropomorphic Responses (y-Axis) as Function of Test Time (x-Axis) and Book Condition (Different Colored Bars), Controlling for Child Age



Note. Anthropomorphism scores ranged from 0 to 7. Error bars show the 95% highest density interval. See the online article for the color version of this figure.

parents, and 229 were initiated by both (13 did not indicate who initiated). This shows that even though parents were the main drivers of reading the book, children were also motivated to read it. We fit a Bayesian logistic regression to examine if the probability of children initiating the book reading (i.e., marking that the book reading was initiated by the child or both the child and the parent) varied by condition and child age. A table with model comparisons can be found in the Supplemental Materials. We found that older children were more likely to initiate the reading of the book, $OR = 1.27$, $b = 0.24$ (0.00, 0.47), probability of direction = 97.54%. We did not find evidence that the condition influenced the likelihood of children initiating the book reading, first contrast: $OR = 1.15$, $b = 0.14$ (−0.36, 0.63), second contrast: $OR = 0.82$, $b = -0.20$ (−0.73, 0.34). This shows that across conditions, children were motivated to read the book.

Correlations

We also explored whether children's gender, performance on the manipulation check (only the images as those were completed by all participants), scariness of viruses, number of times they read the book at home, days in between sessions, parental education, family income, or RUCC score (Rural Urban Community Codes, i.e., a rurality index) were related to their learning. These additional analyses were not preregistered. To do this, we examined Bayesian correlations between these factors and (a) the difference between the posttest and the pretest (as a measure of learning) and (b) the Tacio transfer score. The full table of results can be seen in the Supplemental Materials. We found that more days in between the sessions were related to higher transfer scores, $r = .17$ (.02, .31). This is in line with theories that forgetting specific information helps children abstract and transfer knowledge (Vlach, 2014; Vlach & Kalish, 2014). We also found that children from families with higher income learned, $r = .27$ (.12, 40), and transferred more, $r = .16$ (.00, .30). Surprisingly, we also found that children who scored higher in the manipulation check learned less, $r = -.19$ (−.32, −.04). We followed up on this correlation by examining the correlation by condition. While separately none of the correlations were different from 0 in the anthropomorphic, $r = .12$ (−.14, .36), and realistic conditions, $r = .01$ (−.24, .27), performance on the manipulation check was either positively related or uncorrelated with learning. But in the control condition, performance on the manipulation check was negatively related with learning, $r = .16$ (−.40, .10). This suggests that the overall negative correlation might be due to children in the control condition misremembering that the book included images of viruses. None of the other correlations were different from 0.

Transfer Without Learning

Our preregistered analyses for Tacio transfer included as a predictor how much children knew at posttest. Those analyses allowed us to see whether condition could have had an effect on transfer over and above its effect on learning. However, they do not allow us to see whether there was an effect irrespective of performance on the posttest. Therefore, we explore whether fitting new models without incorporating posttest scores would change the results. Tables with model comparisons can be seen in the Supplemental Materials. The best fitting model included age, condition, and their interaction. As with the posttest, there was an effect of age, $b = 0.27$ (0.06, 0.47), and an interaction between age and the first contrast (comparing the control against the anthropomorphic and realistic conditions), $b = 0.18$ (0.04, 0.33). However, there was no difference between children who read anthropomorphic or realistic books, $b = 0.04$ (−0.89, 0.98), nor an interaction between them and age, $b = 0.03$ (−0.12, 0.18). Therefore, the differences in conditions that we saw at posttest are also present for transfer.

Discussion

Overall, the results of this study showed that young children (5–8 years of age) were able to learn about viruses by reading picture books with their parents at home. Children learned more when the books detailed the invisible processes of illness transmission, and they generalized this information to novel illnesses. Children also transferred their knowledge to properties that were not discussed in the book and to novel viruses. We found little to no evidence that anthropomorphizing viruses influenced children's learning, transfer, tendency to anthropomorphize viruses, enjoyment of the book, or number of times that they read the book. However, we did find that reading the anthropomorphic book led to children being less scared of viruses.

Implications for Children's Understanding of Illness

This study highlights how representing and explaining the invisible processes involved in illness transmission and contagion can help children understand viruses. The control book we developed showed many observable aspects of illness, such as getting sick after being coughed on, developing symptoms after a delay, and relying on preventative measures to stay healthy. Indeed, children were able to benefit from some of this information, with increased performance after being read the control book compared to their pretest performance. However, they learned much more about illness when the books detailed the microscopic processes involved in illness transmission. Both the realistic and anthropomorphic books differed from the control book in depicting viruses, including how they are involved in illness transmission and contagion, and providing mechanistic explanations for delay in symptoms as well as why preventative behaviors are effective. As can be seen in the exploratory analyses, children who were read either the anthropomorphic or the realistic book were better able to explain these processes than children who were read the control book. This underscores the importance of providing mechanistic information to children as it furthers their understanding of different scientific topics (Au et al., 2008; Kelemen, 2019).

Despite the rather limited age range employed in this study, we also found that older children benefitted more than younger children from the book reading. This was likely not due to differences in their prior knowledge of illness as we statistically controlled for this (as assessed by the pretest). The age difference may instead reflect older children's greater information-processing skills (Siegler & Alibali, 2019), allowing them to better attend to, understand, and remember the book content. It is also possible that parents interacted differently during the book readings, as a function of child age. For example, perhaps parents of younger children were less likely to elaborate on the information on the book, instead focusing more on engaging their children's attention. We believe it would be valuable for future work to examine the nature of the book reading interactions themselves, including when and how parents scaffolded or elaborated on the information in the book, as a function of child age. Nonetheless, it is important to note that even the youngest children learned from the book readings and learned more from the anthropomorphic and realistic books than the control book. In short, they still benefitted—just not to the same extent as older children. Extrapolating from our results, it is possible that children who are older than eight might have benefitted even more from the book. It is also possible that these children could have transferred more to a novel virus. Therefore, future studies should examine this with older children.

Our results also demonstrate that children can learn about illness from reading books at home. Although there have been several studies showing that children and their caregivers have conversations about illness (Haber et al., 2022; Menendez et al., 2021), such studies found that caregivers typically focus primarily on emotional support and consequences for everyday behaviors (e.g., why there are lockdowns) rather than scientific mechanisms. Importantly, the present study shows that parent–child interactions can result in substantial child learning about illness mechanisms when caregivers have an age-appropriate, child-friendly informational resource to guide these conversations. Relatedly, this study shows the feasibility of an at-home book-reading educational experience for families. Over 90% of families who participated in the first reading session completed the study; they read the book, on average, about four times in a month (plus the initial reading during the study), and they reported generally positive feelings after reading it. This shows that families engage in this type of educational experience. Therefore, although allowing families to read the book in whichever way felt natural for them (even in the first book reading during Session 1) might have decreased the internal validity of the study, this was compensated by an increase of external validity, showing that even when provided with little guidance from researchers, caregivers were successful in delivering this intervention.

Implications for Anthropomorphism

Contrary to much prior research, we found very little evidence for an effect of anthropomorphism, either positive or negative. Our use of Bayesian data analytic techniques allows us to infer that there was no effect for many of our predictors as zero was part of the distribution of possible effects, and less than 90% of the distribution of possible effects were in the same direction. This means that, for our study, anthropomorphism did not affect children's learning or generalization. There are multiple possible interpretations of this finding. First, it could be that our manipulation of anthropomorphism was not strong enough and that a stronger manipulation could have resulted in a measurable difference. However, in this study, we wanted to match as much as possible the content of the anthropomorphic and realistic books and to avoid providing misinformation. Stronger manipulations of anthropomorphism might present information that is not scientifically correct (beyond the anthropomorphism per se) and would make it difficult to equate in a realistic book. Still, it is an open question whether a stronger manipulation would change the results.

It is also possible that caregivers' extra textual talk might have dampen the manipulation (as reflected in children's occasional errors in the manipulation checks). Prior work has shown that adults use anthropomorphic language to talk about viruses (Labotka & Gelman, 2022) and specifically when answering children's questions (Menendez et al., 2021). Thus, caregivers in our study could have used anthropomorphic language when reading the realistic book, making the two conditions more similar. Likewise, caregivers might have clarified that the anthropomorphism in the book was not accurate, again making the anthropomorphic and realistic books more similar. Given that children in both conditions were *less* likely to anthropomorphize at posttest, it seems more likely that caregivers clarified that the anthropomorphism was not accurate. However, future studies should investigate if this is the case by examining child–caregiver interactions during the book reading or by controlling for the input by having an experimenter read the book. Although these future directions would be useful to understand the role of anthropomorphism in children's learning, it is still notable that, in a setting designed to boost external validity, anthropomorphism did not appear to affect children's learning about illness.

The only difference we found between the realistic and anthropomorphic books was in children's emotional reaction. Specifically, children in this study who received the anthropomorphic text reported being less scared of viruses. This would seem to be in contrast to prior work with adults where anthropomorphism increased people's protective measures due to perceiving the virus as more powerful (Wan et al., 2022). This may depend, in part, on the nature of the anthropomorphism. For example, the images in the book employed in the present study were cute, attractive, and smiling whereas those in Wan et al. (2022) were described as "sneaky," "like well-trained assassins," seeking "locations where they know they can cause the most damage," and "cleverly target[ing] the immune system in order to create more confusion and chaos." Thus, it may be that anthropomorphism heightens a person's emotional response, but the nature of that response (positive or negative) can depend on the specifics of the depiction. At the same time, it is important to note that the condition difference in the present study was fairly small (with most responses being between "not scared" and "a little scared"), so the effect of anthropomorphizing reduced children's already low feelings of being scared. Future research should explore in more depth how anthropomorphism might have affective consequences that could influence children's behavior.

Limitations

The present study should be interpreted in light of its limitations. First, the books were read by caregivers rather than an experimenter. Although this increased the external validity of the work, it also made for less control over the manipulations, therefore, decreasing its internal validity. Accordingly, future work should examine whether differences arise in more controlled conditions. Second, our study did not manipulate different forms of anthropomorphism, only whether the virus was anthropomorphized. Therefore, we cannot claim that all forms of anthropomorphism are inconsequential. Future work should examine the nature of the anthropomorphism (e.g., appealing [as in the present study] vs. dangerous), the degree of anthropomorphism (e.g., animating [as in the present study] vs. having full-blown human features), and the focus of the anthropomorphism (e.g., the virus itself [as in the present study] vs. the "battle" between the virus and the body's immune cells). With regard to the latter contrast, it may be that anthropomorphism about the immune system (in disease symptoms, recovery, and the protective nature of vaccines) would boost learning by providing a framework for communicating biological mechanisms that would otherwise be difficult to understand as they are outside the realm of more familiar sorts of processes.

Third, although we attempted to recruit a diverse sample in terms of socioeconomic status, rurality, and race/ethnicity, 66% of our sample was White, 88% lived in urban areas, 47% had master's or more advanced degrees, and 56% had a family income over $100,000 per year. These percentages for White and urban areas roughly resemble that of the general population of the United States; however, our sample was still more highly educated and had much higher income than the general population. Additionally, even though the percentage of White participants was close to that of the United States, the percentages for other racial groups (particularly Black and Native American participants) were much lower than the general population. As such, we urge caution in generalizing these results to other communities within the United States. Additionally, given the inclusion of only U.S. families, we cannot know if these results would generalize to other countries.

Conclusion

In this study, we tested the effectiveness of an at-home book reading intervention to help young children (5–8 years of age) learn about viruses. Children and caregivers were randomly assigned to read a realistic book that detailed the microscopic processes involved in COVID-19 transmission, an anthropomorphic book that depicted all the same information but using anthropomorphic language and images for COVID-19, or a control book that only showed the visible aspects of illness. Families were sent the book to their homes to read for a month. After a month, children were tested on concepts explained in the book, illness concepts not explained in the book (COVID-19 transfer), and concepts in the book but about a novel illness (Tacio transfer). We found that children learned about COVID-19 by reading the picture books with their parents at home and extended this knowledge to other viruses and that learning was substantially higher for those reading books that focused on invisible aspects of illness. We also found learning did not differ as a function of whether the book used anthropomorphic depictions or not. Altogether, these results demonstrate that carefully constructed picture books can help children learn about complex scientific topics at home.

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