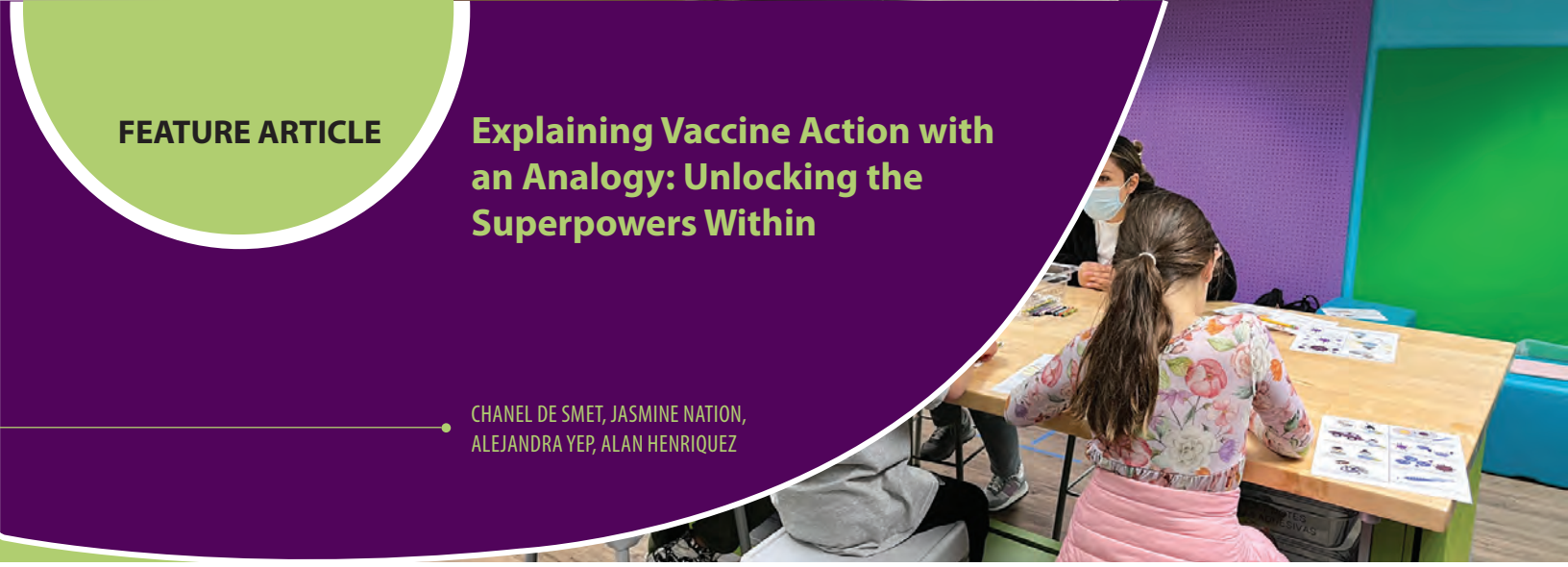
FEATURE ARTICLE

Explaining Vaccine Action with an Analogy: Unlocking the Superpowers Within



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Abstract

This paper presents a novel approach to teaching how vaccines work in the body, and introduces a community outreach project and activity we piloted with youth. Our Nuestra Ciencia program addresses scientific misconceptions among bilingual elementary school children in engaging and scientifically accurate ways. Utilizing analogies and storytelling, one of our lessons simplifies the complex microbiology concept of the mechanism of action of vaccines. We underscore the issue with conveying this concept through accurate visuals, supported by our research that revealed that less than 1% of cartoons available online accurately depict how vaccines work. The analogy we developed and showcase in this paper employs relatable characters: the virus as a robber, the immune system as a superhero, and the vaccine as a "most wanted" poster. The activities include a skit and storyboard session, enabling students to act out the analogy and create their own imaginative scenarios. By targeting young learners, this lesson aims to prevent long-standing misconceptions and empower future generations to make informed decisions about vaccination. Nuestra Ciencia offers a promising model for combating vaccine hesitancy and promoting public health through effective science communication.

Key Words: *microbiology; vaccines; mechanism of action of vaccines; science cartoons; storytelling; Latinx, science communication; community outreach.*

[B]y fostering a solid foundation of understanding of vaccines through analogies, storytelling, and accurate graphics, we can empower future generations to make informed decisions about their health and contribute to a more scientifically literate society.

○ Introduction

The Importance of Microbes in Everyday Life

Microbiology education holds immense value in today's world, providing insight into the invisible, yet impactful, microbial world that surrounds us (Timmis et al., 2019). A strong understanding of microbiology empowers individuals to grasp the profound effect of microorganisms on human health and the environment. Decisions such as requesting antibiotics, eating or avoiding certain foods, giving birth by elective cesarean section, whether to undergo surgeries, and breastfeeding are best informed by a knowledge of how our actions alter microbial populations (Yep et al., 2021). Given the oversized impact of microbes and microbial activities on personal, public, and environmental health, it's clear that "microbiology literacy needs to become part of the world citizen job description" (Timmis et al., 2019, p. 1514).

Despite its significance, K–12 science content standards that set the expectations for what students should know and be able to do, such as the American Next Generation Science Standards (NGSS Lead States, 2013), often fall short in adequately teaching microbiology. Minimal microbiology coverage in primary education around the globe can lead to students entering college with misconceptions (Kahlon et al., 2022). For instance, an Austrian study discovered that even among freshman biology students, only 29% agreed with the statement that vaccination against some viral diseases is possible, with this figure dropping to 12% for non-biology students (Simon et al., 2017; Simon, 2021; Timmis et al., 2019). This finding points to the especially pressing application of microbiology knowledge in the realm of vaccines. With global challenges posed by infectious diseases, a comprehensive understanding of microbiology becomes essential in making informed decisions about public health measures such as vaccination, ultimately protecting individuals and communities.

Given the importance, our bilingual community outreach program, Nuestra Ciencia, helps learners of all ages better understand microbiology concepts. Through analogies and stories, we aim to instill simplified yet accurate microbiology concepts for elementary school children from kindergarten to sixth grade. Utilizing

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analogies and storytelling, one of our lessons simplifies the complex microbiology concept of the mechanism of action of vaccines. By targeting young learners, this lesson aims to prevent long-standing misconceptions and empower future generations to make informed decisions about vaccination.

In the following section, we provide background context on vaccine hesitancy, outline common misconceptions, and highlight the power of storytelling in conveying scientifically accurate models of vaccines.

Vaccine Hesitancy and Common Misconceptions

Vaccines are preparations used to stimulate the body's immune response against infectious diseases (Centers for Disease Control and Prevention, 2021). Vaccines have played a pivotal role in the history of medicine, revolutionizing infectious disease prevention and safeguarding public health. Currently, there are approved vaccines against eighteen viral, seven bacterial, and one protozoan pathogen, with many more in the development pipeline, but no vaccines approved yet for fungal pathogens (World Health Organization, 2024). Since the development of the smallpox vaccine in the late eighteenth century, vaccines have saved countless lives, eradicated deadly diseases, and continue to be a cornerstone of modern healthcare, protecting individuals and communities worldwide (Iwasaki & Omer, 2020). Scientists have estimated that for children born between 1994 and 2013, vaccination prevented 322 million illnesses, 21 million hospitalizations, and 732,000 deaths (Whitney et al., 2014). However, despite the benefits, safety, and widespread availability of vaccines, vaccine hesitancy remains a pertinent issue (Yasmin et al., 2021). Factors contributing to hesitancy include apprehensions surrounding vaccine safety and potential severe side effects, doubts regarding their efficacy, and concerns for the elderly and those with preexisting comorbidities (Dhama et al., 2021). These ideas often originate from misinformation about vaccines and how they are used to control viral outbreaks, which is classified as one of the worst threats to public health efforts (Dhama et al., 2021). Amidst the recent public health crisis of the COVID-19 pandemic, anti-vaccine narratives have proliferated, further impacting vaccine hesitancy in the United States (Puri et al., 2020). COVID-19 vaccine hesitancy varies widely based on region, but is between 12 to 91% of people (Yasmin et al., 2021). To further compound the issue, systematic literature reviews have found little to no evidence supporting truly effective interventions to reduce vaccine hesitancy (Dubé et al., 2015; Sadaf et al., 2013).

While scientists and public health officials have clearly demonstrated the benefits of vaccines, it is difficult to change people's opinions and dispel misconceptions. Specifically, misconceptions regarding the mechanism of action of vaccines tend to be widespread. A recent study surveying college biology students' knowledge about how vaccines work shows that 62% of responses contained inaccurate ideas about the mechanism of action (Kahlon et al., 2022). Among these, the most common (28%) is that the vaccine introduces a certain amount of unmodified virus or disease in the body. Other common misconceptions were that vaccines act as a cure or treatment (11%) or that they directly harm or fight the virus (7%) (Kahlon et al., 2022).

These misconceptions are concerning, considering these are adults studying biology, and the misconceptions are undoubtedly more common in the general public, though there is limited documentation. Even less studied is how these misconceptions take hold in youth and potential ways to reach young learners in order to prevent these long-standing vaccine misconceptions (Stallard et al., 2024).

○ Combating Misconceptions Through Stories and Analogies

It is not surprising how common vaccine misconceptions are given the complexity of the mechanism of action of vaccines and overall challenge of accurately conveying science concepts. One powerful way to combat vaccine misconceptions is to use analogies, considering their track record over the past few decades in science education, helping students understand everything from a dynamic equilibrium to how circuits work (Aubusson et al., 2006). Analogies have communicated many complex biological concepts to a wide range of audiences from young children to adult learners (Aubusson et al., 2006; Federman, 2014; Trnová et al., 2013). Additionally, integrating storytelling in science has proven effective in helping young learners remember complicated science concepts (Hadzigeorgiou, 2016). Science cartoons can also communicate quickly and effectively by using short concise texts, putting subject matter into meaningful contexts, and employing interdisciplinary approaches (Trnová et al., 2013). Cartoons and other drawings can also act as scientific models with explanatory power, an emphasis within NGSS and progressive approaches such as Ambitious Science Teaching. Modeling can foster higher-order thinking about disciplinary content and improved explanations for phenomena and processes (Windschitl et al., 2018).

While researchers tout the benefits of cartoons and other visuals for science education, there are risks of simplifying that can "result in ambiguous and scientifically inaccurate statements" (Trnová et al., 2013). Teachers hoping to combat these misconceptions in their classrooms encounter challenges in finding simplified, yet accurate representations, of the mechanism of action of vaccines. When we were developing our vaccine lesson, we discovered a lack of teaching resources but also basic visuals.

To understand the current state of educational science cartoons representing vaccines, and in turn the images available for free for teachers, we conducted a Google search using the terms "virus vaccine clipart," and examined image results. Our research team, consisting of two professors and two undergraduate researchers, first reviewed search images together to collectively devise a coding scheme of three categories: *neutral*, where a vaccine is depicted alone or with a virus but vaccine and virus are not interacting (Figure 1A); *inaccurate*, where the vaccine is depicted directly being injected into, injuring, or threatening the virus (Figure 1B); and *accurate*, where the vaccine is helping train the immune system against the virus (Figure 1C). We individually analyzed the first five pages of image search, resulting in 106 images depicting a vaccine, coding into the categories of neutral, inaccurate, and accurate. We compared and discussed any discrepancies until we reached a shared interpretation. We found that 27% of these Google images inaccurately depicted the mechanism of action of vaccines, while less than 1% showed the correct representation of vaccines and the immune system, and the remaining 72% were neutral, showing the vaccine but without any interaction with the virus or immune system.

Considering the minimal number of correct representations, we performed ten new searches targeting correct portrayals with search terms including "vaccine mechanism of action," "how a vaccine works," "immune system vaccine," etc. We found only two accurate cartoons. One cartoon showed immune cells lifting weights and jumping rope as a form of training for "a sports game" when the immune system would battle with the virus. The other cartoon depicted an army general training immune cell officers by showing a picture of the virus as the enemy. While these are both powerful

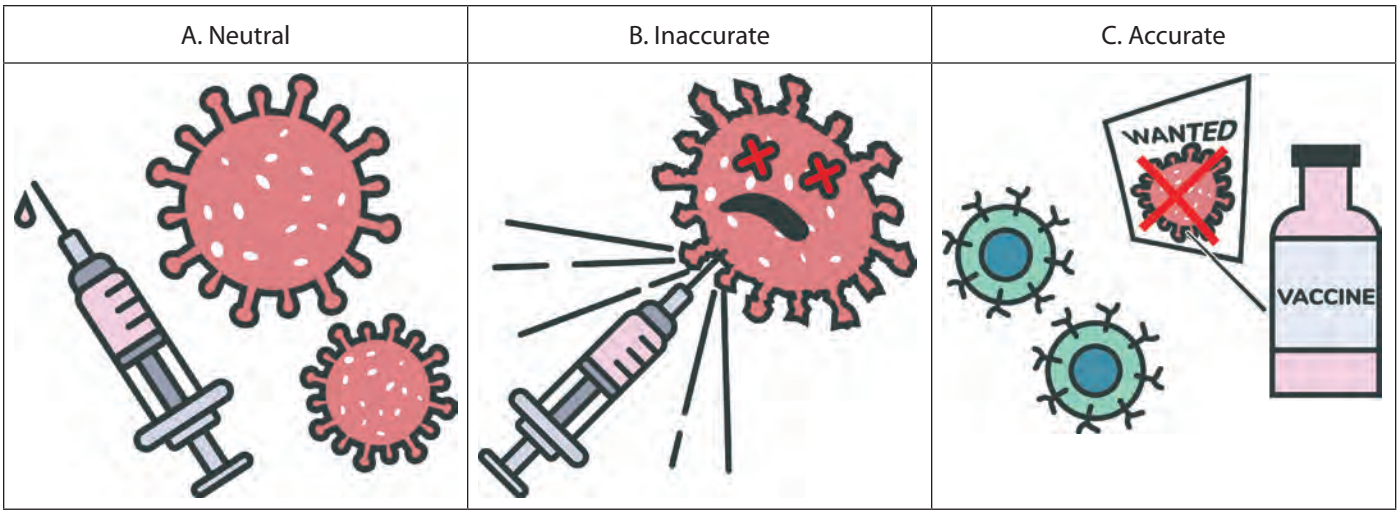

Figure 1. Original artwork by co-author Alan Henriquez illustrating neutral, inaccurate, and accurate cartoons of how vaccines work.

Table 1. Percentage of images and number out of total images portraying the mechanism of action of vaccines as either "neutral," "inaccurate," or "accurate."

Image Category	A. Neutral	B. Inaccurate	C. Accurate
Percentage of Images	71.70% (76/106)	27.36% (29/106)	0.94% (1/106)

analogies, finding them required extensive searching and they were not representative of the majority of images available on Google.

Extensive searching revealed that accurate representations are few and far between, translating to a lack of accessibility for teachers and science communicators. Our findings revealed that the vast majority of cartoons (99%) that would appear for teachers searching for vaccine visuals would not help students understand the mechanism of vaccines. Seeing these results, it is easier to understand why children, and the public in general, would retain misconceptions such as the vaccine directly curing or fighting the virus. These misrepresentations and misconceptions have the potential to unintentionally contribute to vaccine hesitancy. With the global rise in human infectious disease outbreaks since 1980 (Smith et al., 2014), we need better forms of science communication to dispel vaccine misconceptions frequently, and starting from a young age.

○ Our Program: Nuestra Ciencia

Accordingly, our community outreach program, Nuestra Ciencia, develops bilingual science activities that employ storytelling in Spanish and English. Through analogies and stories, we aim to instill simplified yet accurate microbiology concepts for elementary school children from kindergarten to sixth grade. One of these activities uses an analogy and cartoon images to explain the mechanism of action of vaccines and how they work in our bodies, to demonstrate how vaccines protect us from getting severely ill. (For a detailed description of how we co-designed the vaccine activity, including our team's process of developing and refining an appropriately complex, scientifically accurate analogy, see Nation & Yep, 2024). We developed a video, storyboard worksheet, a skit with character costumes, and pre-/post-activity questionnaires, and we have piloted this activity with accompanying materials with elementary students. So far, 85 second through fourth graders in four classrooms have participated in this vaccine storyboard lesson, and an additional 55 fourth through sixth graders have watched the vaccine video and participated in related activities. We have also used the same analogy and video to explain how vaccines work to adults, and found this approach promising for undergraduates and the general public.

Latinx undergraduates are involved in the development and teaching of these materials in Spanish. Therefore, Nuestra Ciencia simultaneously benefits elementary school students by having Latinx undergraduate role models speaking Spanish about STEM, while the undergraduate students benefit from science communication skills and being of service to their community.

Analogy for the Mechanism of Vaccines

Researchers have classified the majority of analogies used in science textbooks as "simple" due to describing rather than explaining the target science concept (Aubusson et al., 2006, p. 17). We present an "extended analogy" to understand the mechanism of action of vaccines that features multiple shared attributes, shows causation, and explains the process (Aubusson et al., 2006, p. 17). Our analogy targets kids in grades two through six and has three main characters—the virus (Figure 2A), the immune system (Figure 2C), and the vaccine (Figure 2E)—and their analogous counterparts. The virus is represented by a robber (Figure 2B), who comes into your house to steal your things, just like a virus can come into your body and make you sick. The immune system is represented by

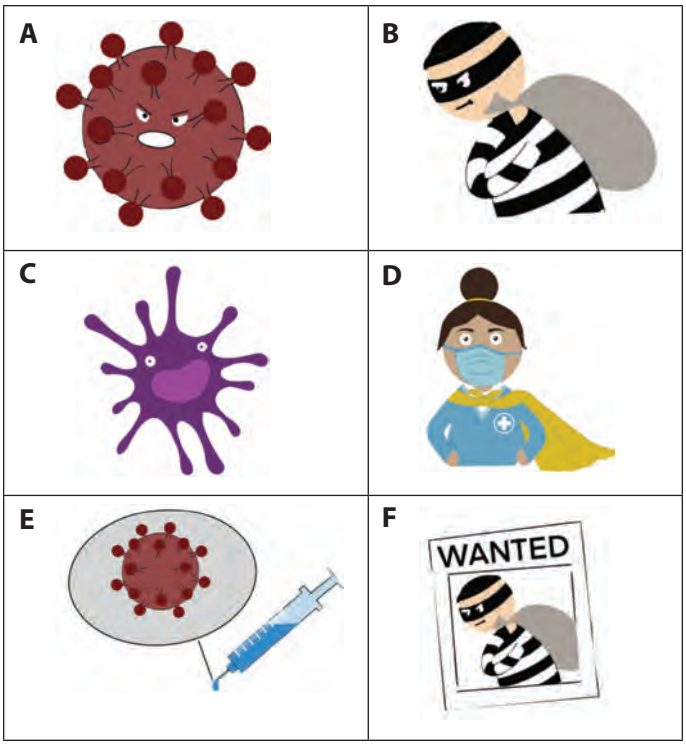

Figure 2. Storyboard characters and what they represent in the vaccine metaphor. Original artwork by Adrian Torres.

the superhero (Figure 2D), who protects you against the robber, similar to how your immune system protects you from the virus. Lastly, there is the vaccine, represented by a "most wanted" poster (Figure 2F) that helps the superhero identify who the robber is based on their appearance. Similarly, the vaccine helps the immune system identify the virus and neutralize it before it can enter cells and cause disease.

In our storyboard, there are panels describing the virus, the immune system, and vaccine, with blank panels for the children to draw in their own robber, superhero, and "most wanted" poster. This interactive activity allows children to be creative and fosters a simple, yet scientifically accurate, understanding of how vaccines work in the body.

We also reiterate several important messages and key takeaways. For example, we teach students that most currently used vaccines do not contain live virus, only a small piece of the virus, such as a protein, and that you will not get sick from getting the vaccine. Your body's immune system might have a reaction to the vaccine, but that is not the same as getting an infection from the actual virus. In our analogy, this is compared to the "most wanted" poster being unable to steal anything like the actual robber would. We also reiterate that the vaccine does not "kill" or "destroy" the virus, the vaccine is instead training your immune system to respond to the virus. These misconceptions regarding the vaccines "killing" the virus are very common, which is not surprising given the prevalence of inaccurate depictions for children and the general public. This is promoted by cartoon depictions of the vaccine syringes "chasing" and inactivating the virus (Figure 1B). However, our analogy directly combats these misconceptions by showing that the immune system, or superhero, is the intermediate step, and the vaccine does not directly kill the virus. This demonstrates that the "most wanted" poster/vaccine is simply a piece of information that your superhero/immune system can use to find the robber/virus.

Skit and Storyboard Activity

Vaccine Video

The lesson starts off with introductions of all the undergraduate members of Nuestra Ciencia. Next, we begin with the vaccine video we have created to introduce our analogy (see supplemental material noted at the end of this article). This vaccine video describes all the major players (vaccine, immune system, and virus) and how they relate to the metaphor ("most wanted" poster, superhero, and robber). The video allows the kids to gain a basic understanding of what we are teaching.

Vaccine Skit

Next, we act out the robber and superhero scenario as a skit. The skit starts off with several students acting as viruses, represented by a koosh ball attached to a headband corresponding to the identity of that virus (green, pink, orange, blue). One student acts as the superhero or immune system, wearing a cape and a mask (Figure 3A). Another student acts as the vaccine, showing the superhero a poster depicting the virus that is causing a disease outbreak (Figure 3B). The "superhero" then uses the "most wanted"

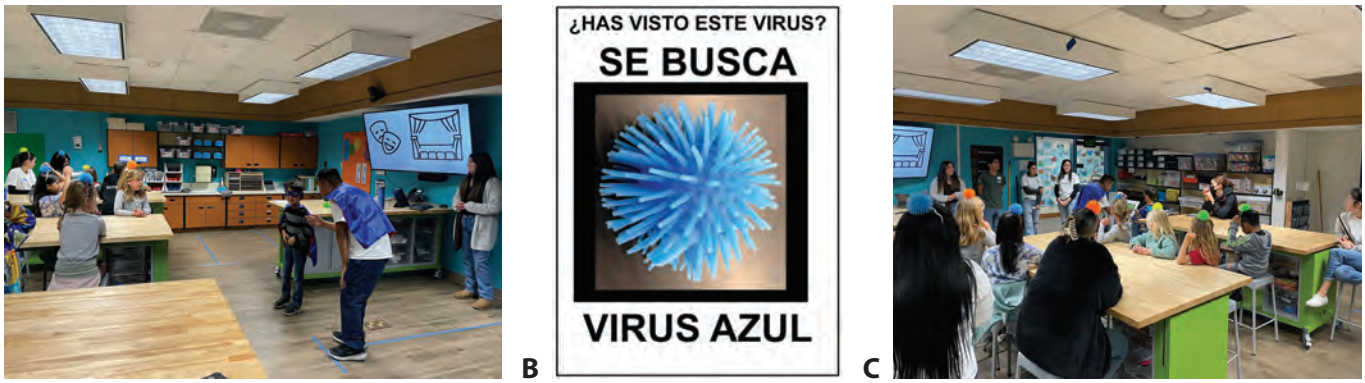

Figure 3. (A) Vaccine skit where a student acts as the superhero using the most wanted poster to find the virus; (B) Sample "most wanted" poster for the blue virus; (C) Viruses are demonstrated by differently colored koosh ball headbands worn by the other students.

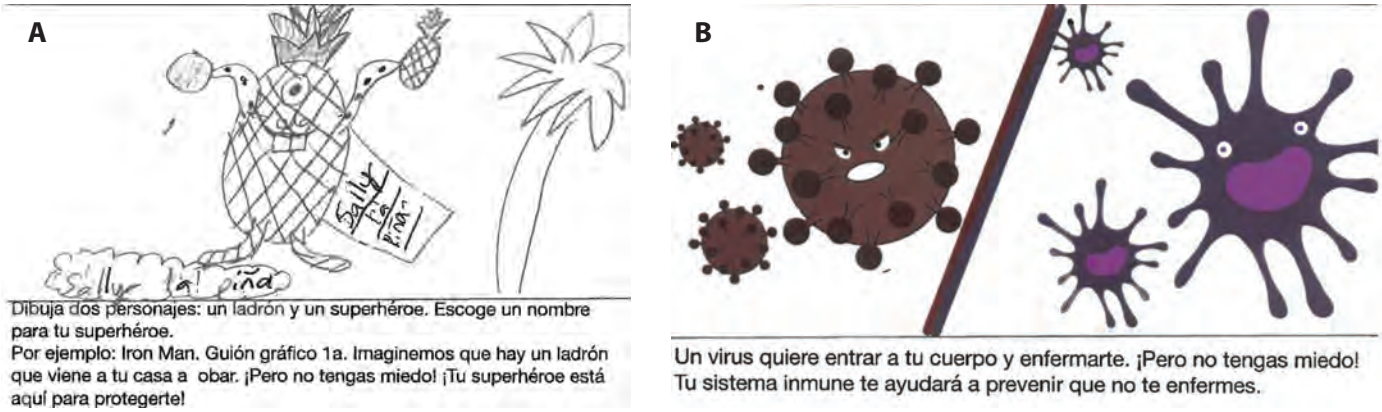

Figure 4. Student drawing of pineapple superhero in storyboard representing the immune system.

poster to identify which of the viruses it needs to find based on its coloration and goes around the room collecting the koosh balls of that color (Figure 3C). This short activity allows the students to see how the scenario works and what the purpose of each character is, while directly interacting with the material. The students yell out to the superhero/immune system where the "virus" is hiding, using the most wanted poster to identify it. The skit reinforces the understanding of how vaccines work through embodied learning, which can be more effective at changing emotional and motivational tendencies in learners (Zhang et al., 2021).

Vaccine Storyboard

We later provide the elementary students with a storyboard for them to replicate the analogy themselves, drawing in their own superheroes (Figure 4B). This allows for the kids to be creative and start to apply the analogy in their own imaginative way. There have been superheroes such as Spiderman, pineapple man, Sonia Sotomayor, and robbers such as a devil, Green Goblin, and even younger siblings (Figure 4A).

Post-Activity Questionnaire

At the end of the lesson, the elementary students are given a post-activity questionnaire that asks about the mechanism of action of vaccines, along with questions such as "Do you feel like a scientist," or "What do scientists look like?" Their responses are compared with the pre-activity questionnaire given to students prior to the lesson, to be completed with their parents at home. The data collection is still an ongoing process, but we hope to capture the students' attitudes toward science and vaccines. Our preliminary data from surveys show that two weeks after the activity, the majority of children in fourth grade could identify the robber with the virus (81%) and the immune system with the superhero (56%). We do not have assessment data from college students, a broader university audience, or second graders due to time constraints and children's literacy.

○ Conclusion

The analogy and storytelling used in our approach were powerful in addressing vaccine misunderstandings. Through the vaccine video, skit, and storyboard, elementary school students grasped how vaccines train the immune system against viruses. Specifically, they gained an understanding that the vaccine, just like the "most wanted" poster, trains the immune system to fight the virus without directly harming the virus or causing disease. The skit and storyboard activity, regarding the process of how the vaccine trains the immune system to find the virus, helped children practice embodied learning to better understand the mechanism of action of vaccines (Zhang et al., 2021). By targeting young learners, we can equip them to communicate their newfound knowledge with their families and other age groups (Timmis et al., 2020).

Reaching students early could prevent misconceptions regarding vaccines that were still seen with students at a collegiate level (Kahlon et al., 2022). Additionally, while the cartoon, video, and skit were aimed at younger children, the analogy itself offers a memorable, clear, and scientifically sound explanation of how vaccines act to prevent disease that could help older students and the general public to understand. This is especially crucial during a global pandemic, when accurate information about vaccines is vital. Our Google search investigation reveals that accurate graphics regarding the mechanism of vaccines are few and far between, only finding two after extensive Google searches. Neither of these visuals were Common Creative, underscoring a lack of accessibility for teachers and science communicators to utilize these visuals. Therefore, by fostering a solid foundation of understanding of vaccines through analogies, storytelling, and accurate graphics, we can empower future generations to make informed decisions about their health and contribute to a more scientifically literate society.

○ Supplemental Material

See our vaccine video at https://youtu.be/L-u8v4rzb94. Additional material and storyboards available upon request. Contact the corresponding author at jmnation@calpoly.edu.

○ Acknowledgments

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