Integrating Arts with STEM to Foster Systems Thinking

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Interest is growing among out-of-school time (OST) educators in integrating the arts into STEM (science, technology, engineering, and mathematics) programming (e.g., Kelton & Saraniero, 2018). Arts-integrated STEM—or STEAM—programming now takes place in a wide variety of OST environments, from relatively institutional learning settings, such as a library, to emergent or fluid settings, such as a pop-up program in a housing development community room.

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Educators often consider OST environments to be conducive to creative and conceptually ambitious STEAM programming because these spaces have the potential to deconstruct rigid boundaries between disciplines that formal education often reinforces.

For the past several years, our team has been designing and studying STEAM programs in OST settings as part of the Health Education through Arts-Based Learning (HEAL) collaborative. The HEAL collaborative is a team of interdisciplinary researchers including university faculty and graduate students with diverse expertise in STEAM education, health sciences, human development, youth programming, educational psychology, and biomedical education. Our team includes a visual artist and several additional consulting visual artists. HEAL works in partnership with Latinx communities in rural-agricultural Washington to increase STEAM education opportunities that blend visual arts with health sciences. We develop programs that integrate art into STEM learning to promote expanded conceptual understanding of STEM content.

In this article, we discuss an OST STEAM program titled Zoom! that we designed and implemented in a summer camp in July 2019. Zoom! used visual arts strategies to support elementary-aged children in thinking about and communicating systems-level ideas related to the human microbiome—the community of single-celled organisms that live on and inside the human body. We start by elaborating on a key design conjecture informing Zoom!, namely, that blending visual arts and science can support systems thinking about complex scientific phenomena. We then describe the summer camp in which we explored this conjecture. Delving into the Zoom! curriculum, we describe the practical framework used to integrate visual arts with human microbiome science and offer examples of three representative activities, along with participants' artwork, that illustrate the potential for arts strategies to engage learners in systems thinking.

Although systems thinking is reflected as a cross-cutting concept in the Next Generation Science Standards, formal educational environments have historically offered few explicit resources for understanding complex systems.

Arts Integration and Systems Thinking

Educators cite a variety of reasons for blending STEM and the arts. Motivation for the STEM-to-STEAM movement includes evidence that arts integration can increase engagement in STEM (Diamond et al., 2015; Graham & Brouillette, 2016; Peppler & Glosson, 2013), improve access for groups underrepresented in STEM (Ludwig et al., 2017; Peppler, 2013), improve learning outcomes (Graham & Brouillette, 2016; Jacobson et al., 2016; Thuneberg et al., 2018), and create a platform for understanding and communicating about social and scientific issues (Allina, 2018; Peppler & Wohlwend, 2018; Sochacka et al., 2016).

This study explores the possibility that arts integration can support systems thinking. A crucial but challenging scientific practice, systems thinking involves the ability and propensity to make sense of complex scientific phenomena by attending to multiple interacting elements across micro to macro scales and exploring how these elements take part in a cohesive whole. For example, the human body is a complex system composed of multiple interacting subsystems—the digestive system, the circulatory system, and so on. These systems, in turn, are composed of multiple interacting organs, which themselves are composed of multiple interconnected parts. Systems have long been recognized as a major conceptual theme running through scientific disciplines (American Association for the Advancement of Science, 1993). Although systems thinking is reflected as a cross-cutting concept in the Next Generation Science Standards, formal educational environments have historically offered few explicit resources for understanding complex systems (e.g., Chi, 2005; Hmelo-Silver & Azevedo, 2006). Systems thinking includes many components (e.g., Hmelo-Silver & Azevedo, 2006; Penner, 2000; Resnick, 1996; Sabelli, 2006). In this article, we focus on three components:

1. Making distinctions and coordinating across scales of analysis
2. Understanding causal links across disparate scales and elements
3. Understanding underlying functions rather than focusing only on superficial structural features

Systems thinking is often described as an advanced skill. However, we took an assets-based view of elementary-aged children, assuming that they are capable of systems thinking. A small amount of research has offered a few inroads into appropriate supports for systems thinking. Jacobson and Wilensky (2006) argue that elementary students need exposure to systems through observable phenomena and everyday experiences. Others have explored systems-thinking pedagogies that emphasize immersive technologies, embodied movement and interaction, and play (Danish et al., 2011).

Calls for more research into systems thinking suggest developing pedagogical methods that blend multiple disciplines (Jacobson & Wilensky, 2006). In designing Zoom!, we were compelled by the possibility that using visual arts to consider scientific phenomena could address this call for a multidisciplinary approach. For example, science education researchers regard drawing detailed representations of the natural world, at both observable and unobservable scales, as a powerful science learning tool because drawing enables learners to think critically about complex causal relations and make their thinking explicit and specific (Ainsworth et al., 2011; Prain & Tytler, 2012). Similarly, art education scholars highlight how arts-based inquiry can be a form of reframing, recontextualizing, and shifting perspectives (Marshall, 2010) in ways that connect across seemingly disparate elements; this process is a core feature of systems thinking.

Summer Camp Program Context

We designed and implemented Zoom! as a four-day summer camp program for children ages 7 to 12. The program took place in a small, rural community in southeastern Washington with a predominantly Latinx population tied to the agriculture industry. Through Washington State University's rural extension system, members of the HEAL collaborative had an existing partnership with a community-based educational nonprofit organization. The partnership provided an opportunity to engage our target audience during an eight-week health and science camp held annually at the community education center. Zoom! met the local organization's need for novel educational programs to diversify its multiweek summer camp. HEAL delivered Zoom! during one of the camp's eight weeks, using the local organization's recruitment and communication systems. The community education center had a fully functioning school building, so it provided the classroom and open spaces we needed to deliver Zoom! through a variety of modalities. The local organization also provided material resources and staffing to support implementation. This support from our local partner allowed HEAL to focus on curriculum implementation rather than organizational and marketing considerations.

We used a team facilitation model in which all sessions included lead facilitators and several aides. Facilitators were members of the HEAL collaborative, and the aides included local community educators and teens from the community who were trained to facilitate programming with younger children. Having teen facilitators enabled us to create a community-connected, multi-age, and multi-generational learning environment. The teens also significantly bolstered the facilitation team's ability to provide a language-inclusive environment. Although many children in the camp were fluently bilingual, others, who were Spanish dominant or monolingual, benefited from the support of Spanish-speaking teens.

Zoom! Curriculum Overview

Broadly, HEAL aims to bolster systems thinking about health and disease, focusing on processes of disease transmission, infection, recovery, and immunity. The human microbiome, besides being a robust example of interconnected biological systems, is also a topic that engages personal experience. These two factors together make it a rich concept for integrating art and systems thinking. The specific scientific focus of Zoom! is the relationship between microbes—both beneficial and pathogenic—and human experiences of health and wellness. The title "Zoom!" was selected to reflect a practice emphasized throughout the program: zooming in and out of human body systems to investigate elements and interactions at different scales.

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During the program week, continuous engagement in topics of art, systems thinking, and microbiology facilitated creation of a virtually seamless narrative of the phenomenon of getting sick. The first day of camp was devoted to introducing microbes in general and the human microbiome specifically, particularly in relation to the body in a healthy state. The next part of the program delved into microbial pathogens and the phenomenon of getting sick. Finally, we touched on the topic of immunity through activities that involved comparing beneficial and pathogenic microbes and understanding their interactions in the human body. Incorporated into the summer camp design were gallery walks in which participants shared their artwork with one another and a culminating art show where they shared their art portfolios with family and community members.

The conceptual understandings Zoom! aimed to foster include recognizing the ubiquity of microbes and microbial communities, connecting groups of organisms to an understanding of symptoms, bridging micro and macro systems, and understanding that not all microbes are bad for human health. Activities prompted participants to explore systems on both micro and macro scales. For example, on a micro level, activities explored characteristics of good (beneficial) versus bad (pathogenic) microbes and how infections can happen when bad microbes reproduce faster than good ones. Bounding this system at a micro level allowed learners to understand microbial interactions on a small scale before applying this understanding to larger-scale phenomena. Other activities encouraged learners to expand their systems thinking. An example of a macro-level activity is when participants created narratives of their experience of getting sick. Their stories included elements of larger related systems, such as the roles of families, rest, healthy food and beverages, and antibiotics.

> Zoom! curriculum designers used three of these approaches to engage learners in thinking and communicating about the human microbiome: depiction, reformatting, and metaphor.

Approaches to Integrating Arts for Systems Thinking

Zoom! used the arts to bridge the micro and macro levels of the phenomenon of getting sick. The program focused on two art modalities: narrative storyboarding, in the form of comic strips, and sculpture, in the form of clay modeling.

We used these modalities in deliberate ways based on Marshall's (2010) five approaches to integrating arts with other disciplines:

1. Depiction: direct representation through illustration, sculpting, and similar means
2. Extension or projection: speculation on or imaginative exploration of how things might be
3. Reformatting: representing subject matter from one discipline using a visual form from another discipline
4. Mimicry: engaging in or imitating disciplinary practices as part of an artistic creation or performance
5. Metaphor: conveying a relationship between seemingly disparate domains through arts media (Marshall, 2010)

Zoom! curriculum designers used three of these approaches to engage learners in thinking and communicating about the human microbiome: depiction, reformatting, and metaphor. These strategies for art integration often overlap; each includes concepts of "interpretation, reinterpretation and/or re-contextualization" (Marshall, 2010, p. 14). All represent ways in which artists reframe concepts by offering a different perspective, an important element in systems thinking instruction. This overlap made Marshall's framework a useful tool for designing an integrated STEAM curriculum. Each of the three Zoom! activities described below focuses on one of the three integration strategies we used.

Depiction + Sick Stories

Depiction, or direct representation, may be the most familiar strategy for integrating art and STEM. To create direct representations of their conceptual understanding, learners think in detail about how parts of a system work together and how these parts connect to other related systems. In the Zoom! activity Sick Stories, learners created a comic-style storyboard to depict their experience of getting sick.

Participants had already been introduced to concepts of scale and zooming in and out of the human body. In creating their six-panel storyboards, some learners addressed micro-scale elements of the phenomenon of sickness by, for example, showing good microbes and bad microbes competing in the human body. Others focused on macro-scale elements, showing the experience of resting or of seeking comfort and care from a family member. Others bridged multiple scales, depicting, for example, feeling sick, going to the doctor, and being prescribed antibiotics to kill the microbes that are causing the illness. Many, that is, adopted the practice of zooming into the human body to explain symptoms and zooming out to portray their experiences. Depicting their personal sick stories encouraged learners to attend to detailed elements of sickness, which they may not have noted with traditional approaches to displaying their understanding, while also connecting these elements through a narrative thread.

Sick Stories offered a context in which learners could directly represent components of sickness and coordinate them at various scales. In the first panel in the comic in Figure 1 (with panels denoted by creases in the paper), the frowning character is visibly upset. The second panel begins to zoom in on the character's body. The third panel continues to zoom into the character's body, where "hero" (beneficial) and "villain" (pathogenic) microbes interact. The symptoms resulting from this microbial interaction are depicted in the fourth panel, where the character is throwing up. The fifth panel depicts another character making a phone call and medicine being prescribed. In the final panel, the main character is clearly feeling better. In this sick story, the young artist depicted co-occurring phenomena in the human microbial system at micro and macro scales. The comic storyboard format enabled the learner to make sense of the phenomenon of getting sick by moving from the internal interactions among microbes to the external experience of having symptoms and receiving treatment.

Recognizing that arts-integration strategies do not exist in isolation (Marshall, 2010), we designed Zoom! to incorporate multiple approaches. In addition to depiction, Sick Stories can be viewed as a practice of reformatting: representing subject matter from one discipline using a visual form from another discipline. Storyboards, a format that is not typically used to depict scientific understanding, can enable learners to see content in a way that may be more meaningful to them than text-based presentations. When learners organize and interpret their experience in different ways, new light may be shed on scientific concepts they are learning (Marshall, 2010).

Reformatting + Microbial Heroes and Villains

Microbial Heroes and Villains explicitly used reformatting as an arts integration strategy. Participants constructed cards, like Pokémon or sports trading cards, to depict beneficial and pathogenic microbes. The target idea is that not all microbes influence the human microbial system negatively. Facilitators encouraged participants to blend real scientific facts and imaginary statistics to represent microbes in the human body as heroes or villains.

Figure 1. Comic narrating the experience of getting sick and being restored to health

This activity is an example of reformatting because trading cards are not a typical format for depicting microbes in scientific discourse. Through this artistic medium, learners both acquired and communicated new understanding of microbes and extended their representation to include other levels of systems thinking. They engaged with causal facets of systems thinking as they highlighted micro-level changes that result in macro-level responses. The trading cards had the additional advantage of being culturally familiar to many participants.

In the trading card depicted in Figure 2, the young artist incorporated real and imaginary elements of microbes to represent a hero microbe. By naming the microbe after English soccer player Callum Hudson-Odoi, the artist brought in personally relevant interests. The illustration also shows understanding of the characteristics of microbes and demonstrates connections among system levels. Specifically, this microbe "creates a barrier for the body that protects from bad microbes" and "can't be destroyed from antibiotics." This second descriptor connects a macro-level system—seeking medication for illness—with the micro level, where the imaginary hero microbe is unaffected by antibiotics. Reformatting allowed this learner to move between imaginary and real characteristics and to attend to different system levels simultaneously.

Other examples of reformatting with trading cards are featured in Figures 3 and 4. Both young artists reference how vitamins are synthesized by beneficial microbes and protect against harmful microbes. The hero microbe in Figure 3 is named "Vitamin Power," an imaginary descriptor afforded by the trading card format. Imaginary elements gave participants personally meaningful ways

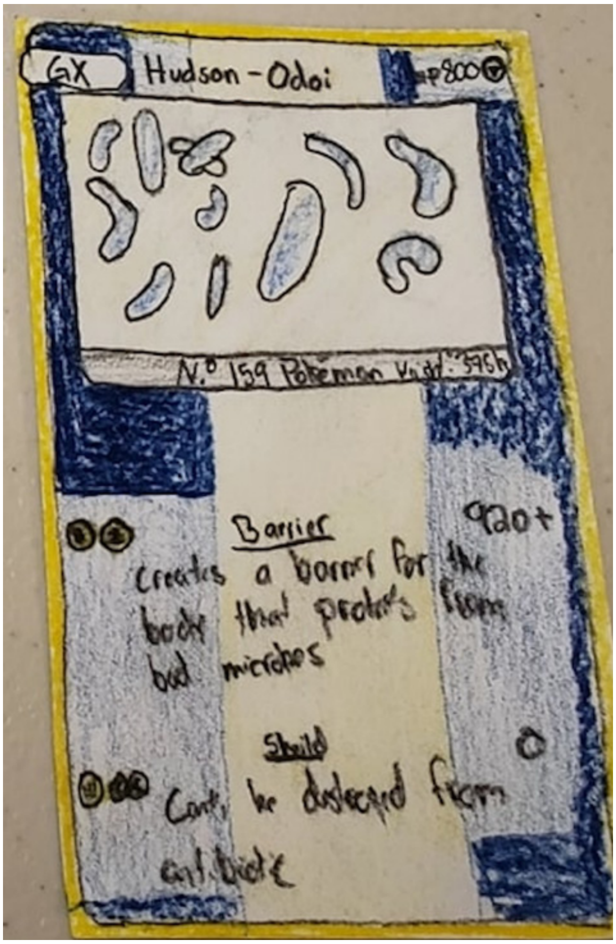

Figure 2. Trading card including imaginary and real elements of microbes

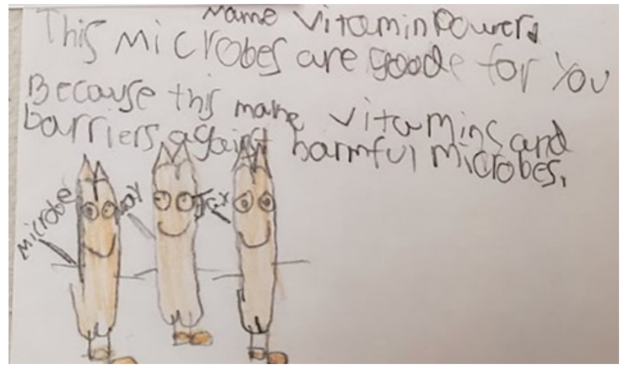

Figure 3. "Vitamin Power" trading card

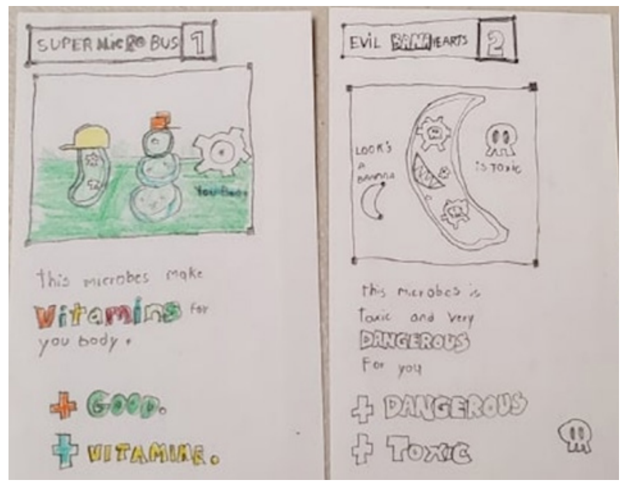

Figure 4. Trading cards highlighting the roles of beneficial and pathogenic microbes

to describe the qualities of the microbes they represented. The name "Vitamin Power" highlights a primary function of many microbes; the description connects this function to interactions with pathogenic microbes.

Many participants opted to depict heroes, or beneficial microbes, in their trading cards. A target understanding for Zoom! was that many microbes have beneficial functions that are necessary for human health. Reformatting in trading cards enabled participants to see these beneficial functions and to explore the interactions between beneficial and pathogenic microbes. They also recognized causal links within and between systems, an important facet of systems thinking. They attended to the ways in which micro-level causes, such as microbes making vitamins, influence the macro level, where microbes are "good for you" (Figure 3) or "very dangerous for you" (Figure 4).

Microbial Heroes and Villains includes Marshall's (2010) approaches of depiction and metaphor as well as reformatting. Depiction is evident in participants' drawings and descriptions of real and imagined qualities of microbes. The metaphor of heroes and villains provided a context in which participants could evaluate the relationships of beneficial and pathogenic microbes to human health and disease.

Metaphor + Body Habitats

Body Habitats aimed to engage participants with the core concept that the human body is a habitat for microbes. We assumed that children would be more familiar with habitats in relation to macro organisms, like people, rather than microbes, which are often viewed as intruders in the human body. To shift this perception, we used Marshall's (2010) metaphor strategy, which she defines as a way to "describe one thing in terms of another," where the linked entities have "similarities and differences and there is a remote connection" between them (p. 17). We designed Body Habitats to support learners in connecting, on the one hand, their everyday and cultural experiences in their homes with, on the other hand, the human body as a habitat for microbes.

In Body Habitats, facilitators gave participants a collection of microscopic images of tissues from the human small and large intestine and from the trachea and other parts of the respiratory system. They asked learners to create dioramas, using shoeboxes and diverse art materials, to communicate that the human body is a home for microbes. The program had already developed some foundational knowledge about the diversity and quantity of microbes in the human microbiome.

Marshall (2010) presents metaphor as an art integration strategy suitable for middle or high school students. However, the elementary-age participants in Zoom! successfully integrated metaphor with scaffolded support. We gave learners the metaphor of their own bodies as homes for microbes, so they didn't have to develop the metaphor themselves. Rather, they used their dioramas to expand on the metaphor, transferring their existing understanding of what comprises a home to their exploration of how microbes reside in the human body.

Participants took varied approaches to the activity. For example, the art in Figure 5 shows microbes inhabiting the human trachea. This participant has used depictive strategies to represent components of the trachea by, for example, sculpting the cilia as orange clay protrusions. Trachea microbes take the form of purple, red, and blue pom-poms with googly eyes. This young artist has taken up the metaphorical intent of the activity by incorporating features of the everyday experiences of macro-organisms (that is, family members—complete with eyes) cohabiting a place.

Figure 5. Diorama of the trachea with googly-eyed microbes

Figure 6 shows three dioramas in which young artists used a different strategy, incorporating material components of human homes in their dioramas. They connected human homes with microbial habitats by creating detailed scenes of rooms with couches, televisions, beds, showers, and rugs. In one of the scenes,

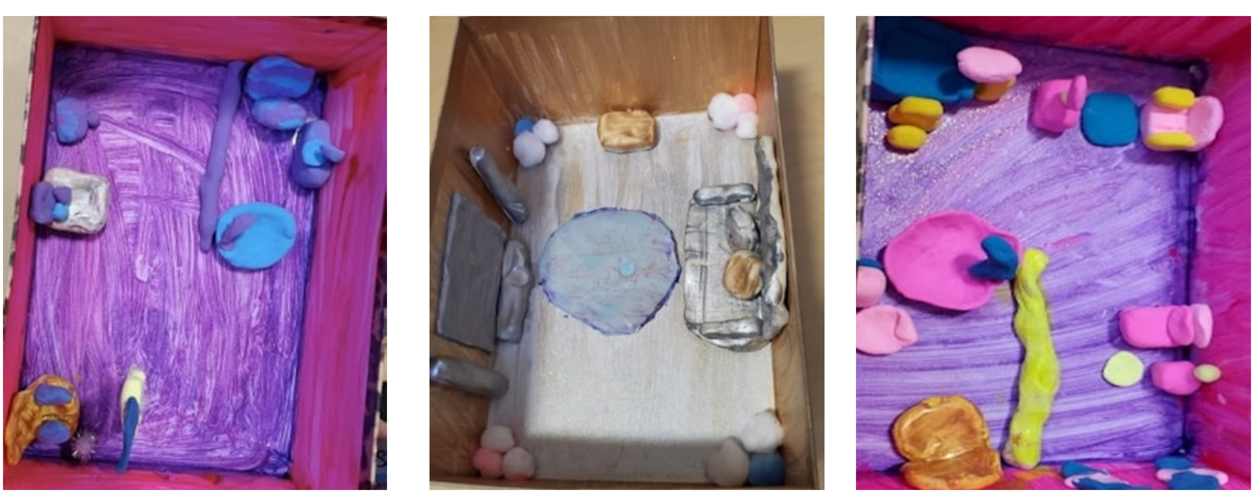

Figure 6. Dioramas with human furniture

pom-poms again depict microbes, this time lounging in the corners of a living room.

Educational researchers identify as a sign of complex systems thinking the ability to move from thinking solely about structural features of a system, such as the shape and location of cilia in the trachea, to understanding the functions of system components in relation to one another, for example, depicting cilia as part of a habitat for microbes (Hmelo-Silver & Pfeffer, 2004). In Body Habitats, participants used metaphorical connections between familiar and unfamiliar places to make that connection.

As with the other Zoom! activities, Body Habitats incorporates not only metaphor but also other art integration strategies. Many dioramas used depiction, directly representing microbes within the habitat. Reformatting was apparent in the recontextualization of a microbe habitat into a diorama.

Arts Integration to Promote Systems Thinking

STEAM integration allows both real and imagined recontextualizations and connections that have potential to support systems thinking. Employing arts-integration strategies, such as depiction, reformatting, and metaphor (Marshall, 2010), may support young people to make distinctions between and coordinate among multiple scales of analysis. They can also help learners to understand causal links across disparate scales and elements and to attend to underlying functions rather than focusing solely on superficial structural features.

The Zoom! activities Sick Stories, Microbial Heroes and Villains, and Body Habitats were designed to bridge STEAM disciplines. Our interpretation of the resulting artwork illuminates a potential mutualism between arts-integration approaches and systems thinking. Each activity demonstrated potential to support at least one facet of systems thinking. Collectively, these activities may have helped participants develop complex systems thinking that considers multiple interacting levels.

Our assets-based approach engaged elementary-aged children through observation of everyday phenomena, interaction, and play. In line with arguments made by scholars such as Danish et al. (2011), we found that these children could engage with systems thinking through arts integration with appropriate scaffolding and support. Responding to calls in science education for detailed representations of observable phenomena and in art education for reframing, recontextualizing, and shifting perspectives, Zoom! sheds light on the ways in which arts integration can foster development of systems thinking.

A primary challenge that emerged in our study was the difficulty of evaluating learners' systems thinking from their art alone, without other data such as participant interviews. Interpretation of how the artwork communicated understanding of the human microbial system rested solely with the observers—that is, with us, the curriculum designers, facilitators, and researchers for the project. Conclusions about children's thinking require inferential leaps; conclusions from artworks alone require bigger leaps. The challenge, as in evaluating any artwork, is to separate intent from what is actually presented. The interpretations of participant artwork in this article are not clear windows into the young artists' minds but rather suggest what the art might communicate to a viewer. Others who study art integration for systems thinking may consider including annotations, dialogue bubbles, or mini video presentations to allow learners to elaborate on their artistic intent and the scientific ideas they hope to communicate.

A potential concern with non-depictive arts integration strategies like reformatting and metaphor is that they might lead to scientifically inaccurate understandings—that microbes have googly eyes or that human body systems have living room furniture. Our assets-based view of children acknowledges their ability to understand the difference between literal and imaginative meanings. To be sure of our interpretation, we also used traditional learning assessments. Results of a pre- and post-participation questionnaire showed statistically significant gains in learners' understanding of microbial science. Though their artwork portrayed imaginative recontextualizations of scientific phenomena, participants translated these concepts and practices into accurate understanding of scientific content.

The design of Zoom! was based on one key conjecture: that blending visual arts and science can support systems thinking about scientific phenomena. Our observations of program participants' artwork, together with the results of the pre-post content assessment, suggest that elementary-aged children in OST settings can engage in systems thinking through STEAM activities. The conjecture deserves continued exploration. As children are increasingly exposed to complex socio-scientific phenomena, OST environments may play a key role in prompting systems thinking through creative, interactive, and fun approaches.

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