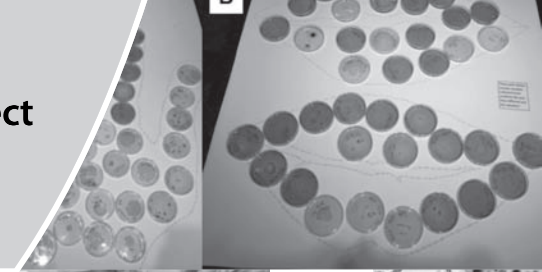
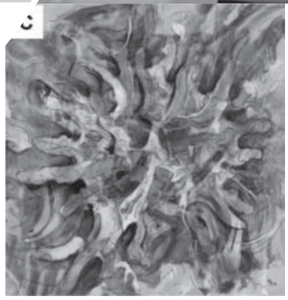
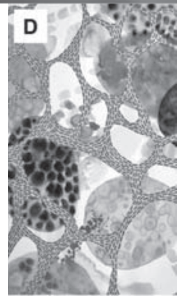
RESEARCH ON LEARNING

Microbe Art Can Educate & Correct Misconceptions about Microorganisms







NABT BioClub RECOMMENDATION

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Abstract

Microorganisms are diverse, minute, simple life-forms that generally cannot be seen by the naked eye and require the use of a microscope to be visualized. They have a great impact on all other life-forms. Their tiny size conceals them from us, engendering misunderstanding and fear due to the diseases caused by only a tiny minority of them. We conceptualized and installed an art exhibition called Tiny Enormous *with the intent to educate our campus community and correct misconceptions about microorganisms.* Tiny Enormous *utilized a variety of artistic media, including paint, sculpture, video, and preserved plates, to display the diversity and ubiquity of microbes, and a series of infographics to illustrate key concepts and correct misconceptions. We surveyed visitors at the opening and closing receptions to examine their knowledge about, and perceptions and attitudes toward, microorganisms prior to and after visiting the exhibition. Respondents who had viewed* Tiny Enormous *demonstrated better knowledge of microbiological terms and concepts and self-reported increased knowledge about microorganisms compared to those who had not. Perceptions that microorganisms were harmful did not differ between subjects prior to and after visiting* Tiny Enormous, *possibly because of the exhibition's information about "superbugs." Our results suggest that artistic representations of microorganisms are effective educational tools for both academic and nonacademic audiences.*

Key Words: *microbe art; microbiology; science and the public; superbugs.*

○ Background

We live on a planet dominated by microorganisms – diverse, minute, simple life-forms that generally cannot be seen by the naked eye and require the use of a microscope to be visualized (Slonczewski & Foster, 2013). Prokaryotes, unicellular organisms with no true nucleus, outnumber eukaryotes significantly (Dykhuizen, 2005; Nature Reviews Editorial, 2011). For instance, the gut microbiota in humans outnumber all the other cells of the human body (Quigley, 2013; Sender et al., 2016), and our current understanding of the "tree of life" suggests that prokaryotes comprise a substantial majority of taxonomic diversity (Hug et al., 2016; Locey & Lennon, 2016). Microorganisms have been discovered in every conceivable environment, including soil, our bodies, and extreme environments such as deep oceans and frozen lakes (Whitman et al., 1998; Quigley, 2013). Microorganisms drive many processes, such as nutrient cycling, in both terrestrial and aquatic ecosystems as mutualists and decomposers, and the value of ecosystem services provided by microorganisms is immense (Alongi, 1994). The impact of microorganisms on humans is also great, as microorganisms play important roles in producing food, digesting food, abating inflammation, improving mood, and maintaining normal weight, among others (Ley et al., 2005). While the benefits of microbial communities are well known to scientists, less is known about whether nonscientists recognize the benefits of microorganisms. Conversely, microorganisms are universally recognized as etiological agents of many human infectious diseases (Doolittle, 2002; Fraser-Liggett, 2005) as well as diseases of pets, livestock, crops, and wildlife (Raffaele et al., 2010; Relman, 2011). Public knowledge and attitudes toward microbiology are derived primarily from the media (Hawkings et al., 2007), rather than from direct communication by scientists.

"We encourage others to consider the use of art galleries for outreach and education in traditional STEM disciplines."

Considering the great impact of microorganisms on human life, three fundamental objectives drove the work reported here: (1) to determine how best to communicate the positive impact of microorganisms to a broad audience, (2) to gauge the general public's knowledge of microorganisms, and (3) to assess the effectiveness of an art exhibition as a method of public outreach and education. The Roy C. Moore Art Gallery, on the campus of the University of North Georgia, presented an appropriate public space in which to carry out this investigation. In keeping with part of the mission of the gallery, "to cultivate an appreciation of contemporary artistic practices"

The American Biology Teacher, Vol. 82, No. 3, pp. 162–169, ISSN 0002-7685, electronic ISSN 1938-4211. DOI: https://doi.org/10.1525/abt.2020.82.3.162.

(University of North Georgia, 2019), our interdisciplinary team of three, in partnership with the gallery's director, Victoria Cooke, planned and implemented this exhibition over the course of a year. The result was *Tiny Enormous*, a month-long art–science exhibition of both visual evidence and imaginative interpretations of microorganisms. Art using microorganisms themselves has existed since the early 20th century (Fleming, 2007; Dunn, 2010).

Art and science may seem to exist in categorically separate spheres that have little in common, as suggested by the physical separation of art and science departments on university campuses. However, there is common ground in the creation of art and the acquisition of scientific knowledge, including intellectual curiosity about the world, creative leaps (i.e., imagination), and experimentation. The connections between art and science are deep, and these connections have been interwoven to varying degrees throughout human history. We find more integration of these disciplines in certain historical moments than in others. One such moment was during the Renaissance, as reflected in the works of da Vinci, Brunelleschi, and Michelangelo. Another such period of renewed interest in connecting the arts and sciences occurred around the mid-18th century (Miller, 2014).

Today, we can easily find examples of art and science intermingling to educate and entertain broad audiences about misunderstood or little-known organisms. Art in the natural sciences has evolved from traditional illustrations of form to many new kinds of visual representation of both form and abstract concepts. For instance, the American Society for Microbiology hosts an annual Agar Art Competition. Numerous blogs of scientists, artists, and enthusiasts feature pictorial imagery actually made with microbes (e.g., Gregory et al., 2009; Park, 2018; Racaniello, n.d.). Recent literature on the mutual interests of art and science includes Elaine Strosberg's (1999, 2015) *Art and Science*, Sian Ede's (2005) *Art and Science*, and Artur I. Miller's (2014) *Colliding Worlds: How Cutting-Edge Science Is Redefining Contemporary Art*. Cross-disciplinary collaboration is currently encouraged in institutions of higher education as well as in K–12 education, as evidenced in the increasing numbers of STEM/STEAM (Science, Technology, Engineering, Art, and Mathematics) certified schools (STEAM Edu, 2015). Since 2008, the STEAM initiative, advocated early on by the Rhode Island School of Design (RISD), has supported this integrative approach to education as well as other activities (RISD, 2018). As of April 2018, there are over 3200 self-reported practicing STEAM educators, scientists, and policymakers (STEM to STEAM, 2018).

Tiny Enormous, as one example of the possible outcomes when the arts and sciences work together, fits into the STEAM model and represents a trend that is gaining momentum. Artists are collaborating with other disciplines with increasing frequency (Calvert & Schyfter, 2016; Eldred, 2016; Jeffreys, 2018) to enhance their ability to communicate with a broader audience. Likewise, as vehicles for human communication, the visual arts can serve scientists' needs to disseminate research from the laboratory to a wider audience (Rees, 2008; Yetisen et al., 2015). Given the striking immediacy that a well-composed visual image can have, the idea of using visual art to reach a broad audience seemed an intuitive direction for our own work to take. We found several examples of art–science exhibitions in the literature (Monoyios, 2015; Park, 2018), and we chose microorganisms as a timely topic for our own exhibition. That choice was affirmed when we came across an article about a South Carolina–based marine scientist and artist, Julia Bennett, who uses photography as a medium to reach a wide public. Slobig (2014) writes that "the photographer believes that some of us are far more likely to be affected by a single, elegant image than a powerfully written scientific paper." We share this interest in finding ways to make science more accessible to a broader audience, including nonscientists.

Here, we define and assess the educational outcomes of *Tiny Enormous*. The exhibition was installed as a STEAM project that integrated art and design with microbiology. Our primary goal was to educate both our university and the community at large about microorganisms.

○ Installation & Promotion of *Tiny Enormous*

Tiny Enormous was installed the week of August 21, 2017, and was opened to the public on August 30. The exhibition was open for 21 days, closing on September 27. We publicized *Tiny Enormous* with posters on most of the academic buildings on our campus, as well as with electronic postings on the university notice board and website and on the websites of newspapers in Gainesville (GA) and Atlanta. Word of mouth was also used extensively to attract students, faculty, and staff. Receptions were held on both the opening and closing dates. At the opening reception, we allowed visitors to kiss agar plates or have their fingertips swabbed; these microbial samples were cultivated overnight to make two hand- and lip-shaped mosaics, preserved with epoxy ethane, for use in the exhibition (Figure 1A, B). At the closing reception, we gave a 15-minute presentation about the artworks.

Thirteen artists from six states (Georgia, Indiana, Kentucky, New York, South Carolina, and Tennessee) submitted 35 original works, including five by one of us (McIntosh). These artworks incorporated several types of media, including clay, video, oil paintings, acrylic paintings, watercolor paintings, etchings, and mixed-media works. Each of the artists interpreted microorganisms as subject matter in unique and visually compelling ways. Some of the artworks featured representations that were based on observations of various microbes; for example, Allyson Winter's acrylic paintings of yeasts for making beer and wine depict them as vibrantly colorful abstractions. Forms resembling yeasts cascade across the composition. Similarly, Lennon Michalski's (Figure 1C) layered and poured acrylic paintings show the polio virus, its form clearly described in paint and pen on a wood panel. Some of the works included are imaginative interpretations of microorganisms, perhaps not clearly recognizable as any one specific kind of microorganism, but clearly referring to an active microscopic world in flux, utilizing creative license to create a compelling image aiming to ignite curiosity rather than to illustrate. The five watercolor and gouache paintings by Erin McIntosh (Figure 1D) operate in this way, attempting to convey the diversity, complexity, and ubiquity of the microscopic world in all its dynamism.

Tiny Enormous used three methods to convey information. First, and most importantly, the art pieces themselves displayed the form and diversity of microorganisms. Second, we wrote a series of 10 short informational pieces that shared our fundamental

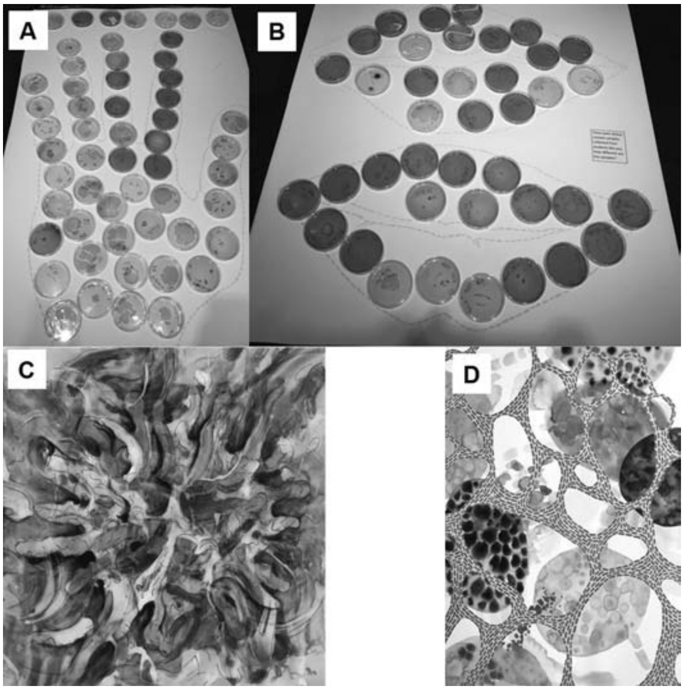

Figure 1. Representative components of the exhibition *Tiny Enormous*, presented at the Roy C. Moore Art Gallery in August–September 2017. (**A**) "Hand" and (**B**) "Lips" mosaics of cultured Petri plates (the outlines for these were created by Erin McIntosh). (**C**) Original art by Lennon Michalski: *Polio Virus*, water-based pigment and medium on panel, 10 × 10 inches. (**D**) Original art by Erin McIntosh: *Microbe no. 4*, watercolor and gouache on paper, 30 × 22 inches, showing a mix of microbes, the clearest being chains of bacilli (rods) in a web-like pattern.

concepts along with interesting microbiology facts (Appendix). These were posted in the gallery at strategic locations to lead the visitors through the exhibition, near appropriate pieces when possible. Third, we wrote and printed trifold pamphlets about microbiology and the exhibition that visitors could keep. We were able to assess the effectiveness of the first two methods.

Table 1. Selected fundamental statements from the microbiology concept inventory (Paustian et al., 2018), and our assessment items that align with each.

Fundamental Statement	Assessment Items
14. The growth of microorganisms can be controlled by physical, chemical, mechanical, or biological means.	a. What are antibiotics used for? b. What is a "superbug"?
20. Microorganisms are ubiquitous and live in diverse and dynamic ecosystems.	c. Give the definition of "microorganism." d. Name some types of microorganisms. e. List some places where microorganisms are found.
23. Microorganisms, cellular and viral, can interact with both human and nonhuman hosts in beneficial, neutral, or detrimental ways.	f. List all of the ways that microorganisms and humans can interact or affect each other. g. What percentage of microorganisms are harmful to humans? h. Rate the harmfulness of microorganisms on a scale of 1–10, 10 being highest.
27. Because the true diversity of microbial life is largely unknown, its effects and potential benefits have not been fully explored.	i. What percentage of all estimated species of microorganisms are known to science? j. Why don't scientists know all the species of microorganisms that exist? k. Rate your knowledge of microbiology on a scale of 1–10, 10 being highest.

○ Survey Methods

We invited visitors at both receptions to complete anonymous surveys about microorganisms and their levels of microbiological knowledge and opinions (perceptions). Questionnaires consisted of 11 items, developed by us to assess our first two methods of conveying information. We developed the questionnaires prior to the validation of the microbiology concept inventory (Paustian et al., 2018); however, our survey items align closely with its fundamental statements (Table 1). Visitors also provided information about their affiliation with our university, if any.

Our surveys provided both qualitative and quantitative data that we compared between respondents who had not visited *Tiny Enormous* ("before" group) and those who had ("after" group). Although we initially attempted a design in which we compared paired "before" and "after" answers for each visitor, we had to, instead, compare "before" and "after" as two independent groups due to large numbers of visitors leaving after walking the installation or walking the installation before taking a survey. The type of analysis used to compare the two groups varied based on the items and the data they provided. Most of the items (items a–g and item j; Table 1) prompted respondents to provide a definition or a list. These items provided qualitative data that were coded into quantitative data. In these responses, we identified three to eight key words and phrases (e.g., *microscopic*, *virus*, *antibiotic resistant*) that appeared in multiple responses for each item. We then divided the number of times each key word was used in responses to each item by the total number of responses to that item, which allowed us to calculate the percentage of respondents using each key word. For instance, 35 of 53 respondents (66%) referred to "illness" in answer to item f, which asked the subject to list all the ways that microorganisms and humans can interact or affect each other. Each of these frequency values could be compared between groups with a chi-square test of independence. We also used Wordle (http://www.wordle.net) to produce word clouds to visually compare the frequency of key words appearing in responses before and after visiting *Tiny Enormous*. The remaining items (g, h, i, and k) provided quantitative values. These values were compared between groups with Kruskal-Wallis tests, since self-ratings were treated as counts with an error distribution that prohibited *t*-tests. Kruskal-Wallis tests were used to compare the number of terms listed for the three items (d, e, f) that prompted respondents to create lists.

○ Survey Results

A total of 125 visitors attended the two receptions and were asked to share their affiliation with our university. The majority (75%) were students, and 28 different majors were represented in this sample. Students pursuing an art-related (n = 30), biomedical (n = 22), or allied health (n = 12) focus were the most common visitors. Of the 23 visitors who were university faculty or staff, the highest numbers were employed by the biology (n = 7, faculty only) or art (n = 5, both faculty and staff) departments. The remaining visitors affiliated with the university were staff, including public relations and administration. No data were available for the total number of visitors to the installation, outside of the two receptions. Other visitors at the receptions included family and artists. Complete or mostly complete surveys were returned by 53 attendees of the opening reception and 33 attendees of the closing reception. The results presented below are organized according to four "fundamental statements" from the microbiology concept inventory (see Table 1).

Results for Fundamental Statement 14: The growth of microorganisms can be controlled by physical, chemical, mechanical, or biological means.

The misuse or overuse of antibiotics is a contributing factor in the development of antibiotic resistance, including the rise of multi-drug-resistant bacteria, informally called "superbugs" (Harrison & Svec, 1998). Relatively harmless bacteria (such as *Staphylococcus*, *Enterococcus*, and *Acinetobacter*) can develop resistance to multiple antibiotics and cause life-threatening infections. Respondents who had visited *Tiny Enormous* were almost 50% more likely to specifically mention antibiotic resistance when defining *superbugs*, and also more likely to use the words *evolve(d)* or *evolution*, compared to respondents who had not visited the installation. Although many respondents did not specifically say that superbugs are bacteria, the inaccurate statement that superbugs are viruses was made only by respondents who had not yet visited *Tiny Enormous* (Figure 2). Respondents who had not visited the installation were also more likely to state only that antibiotics treat "illness" without mentioning microorganisms and more likely to repeat the dangerous and widely held misconception (World Health Organization, 2015) that antibiotics treat viruses (Figure 3).

Results for Fundamental Statement 20: Microorganisms are ubiquitous and live in diverse and dynamic environments.

When prompted to define *microorganism*, over 90% of respondents in both groups indicated that microorganisms are "microscopic" or "small" (or a synonym, e.g., "tiny"). Those who had visited *Tiny Enormous* were 44% more likely to correctly (per the definition in Slonczewski & Foster, 2013) state that microorganisms are too small to be seen with the unaided eye (Figure 4). On average, respondents could name only 1.6 types of microorganisms before visiting *Tiny Enormous* and at least two types of microorganisms after visiting, an increase of 26% that was significant according to a Kruskal-Wallis test (P = 0.04). Almost all respondents (~90%) recognized that bacteria are microorganisms. Respondents who had visited the installation were more likely to name other

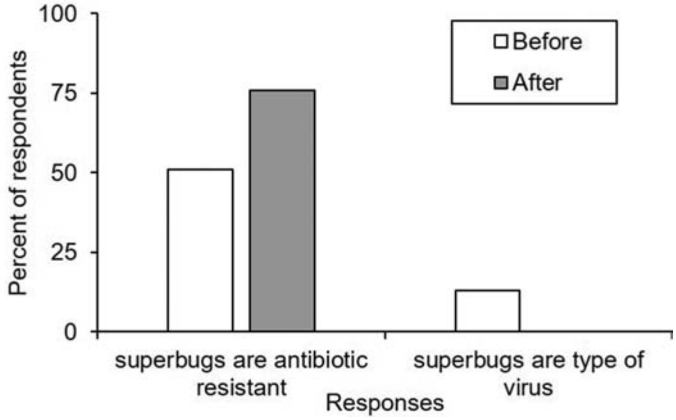

Figure 2. Responses to the assessment item "What is a 'superbug'?" before and after visiting *Tiny Enormous*.

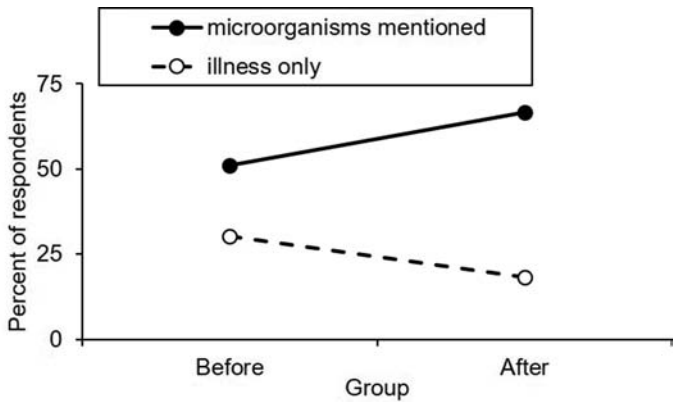

Figure 3. Responses recognizing that antibiotics are used to control microorganisms, before and after visiting *Tiny Enormous*.

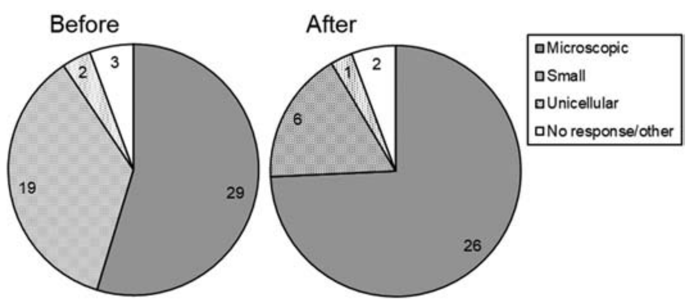

Figure 4. Relative frequencies of word use in respondents' definitions of "microorganism" before and after visiting *Tiny Enormous*.

microorganisms besides "bacteria" or list types of bacteria (Figure 5). Other responses included "plankton/algae," "animals" (three-fifths listed tardigrades), "yeast," and "Archaea." Overall, both groups were able to respond that microorganisms are abundant and found in every conceivable environment. Visiting *Tiny Enormous*, which displayed colonies cultured from inanimate objects, also seemed to influence respondents to mention more often that microorganisms can be found on inanimate objects.

Results for Fundamental Statement 23: Microorganisms, cellular and viral, can interact with humans in beneficial, neutral, or detrimental ways.

Microorganisms are the causative agents of diseases such as bubonic plague, Lyme disease, foodborne infections, and many others, and we predicted that most respondents knew that. The majority of respondents, 66%, did state this fact, regardless of whether they had visited *Tiny Enormous*. After infectious diseases, both groups were most likely to mention positive interactions, such as normal flora protecting against infectious disease and aiding digestion (Figure 6). Respondents who had not yet visited *Tiny Enormous* were more likely to mention that microorganisms aid digestion and prevent infection, while those who had visited were more likely to mention that microorganisms help make food and drinks, produce antibiotics, and mitigate pollution (Figure 6). While many respondents overestimated the percentage of microbial species that cause infectious disease, those who had not visited *Tiny Enormous* overestimated by a greater extent, with one respondent saying that 100% of microorganisms are pathogens (Table 2). After visiting *Tiny Enormous*, respondents were more likely to answer that a very small percentage of microorganisms have any negative effect on humans. Both groups of respondents gave the same rating for the harmfulness of microorganisms, which did not differ according to a Kruskal-Wallis test ($P = 0.38$). The range of harmfulness ratings was 1–10 in both groups.

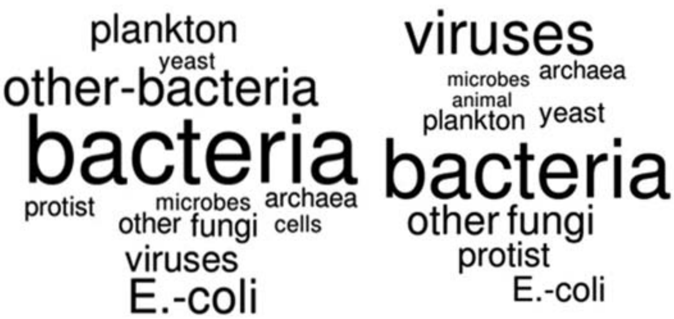

Figure 5. Word cloud representing how often various types of microorganisms were listed by respondents before (left) and after (right) visiting *Tiny Enormous*.

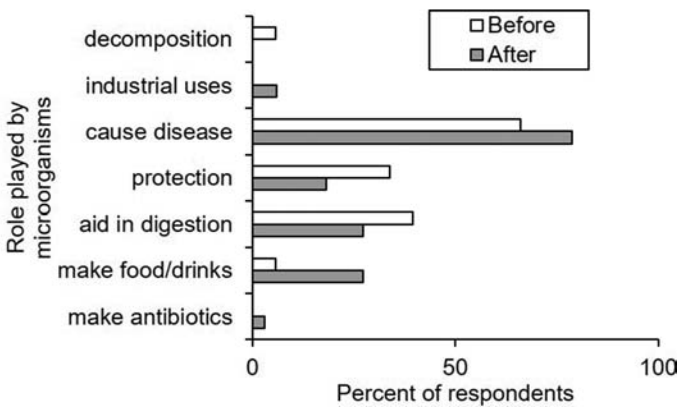

Figure 6. List of answers to the assessment item prompting visitors to list the roles played by microorganisms, before and after visiting *Tiny Enormous*.

Results for Fundamental Statement 27: Because the true diversity of microbial life is largely unknown, its effects and potential benefits have not been fully explored.

A broad variety of answers were given for our assessment item about the percentage of microorganisms known to science, including "don't know," "small," and "millions." When respondents gave a percentage, *Tiny Enormous* visitors were more likely to respond with a lower percentage (especially <1%) than those who had not yet visited (Figure 7). This question does not have a clear answer other than <1%, since the estimates of total microbial species diversity range from $1*10^4$–$1*10^8$ total species, with fewer than $1*10^4$ species known to science (Mora et al., 2011; Locey & Lennon, 2016). Both groups indicated that they knew little about microbiology, although the group that had visited the installation did report a higher evaluation of their own knowledge according to a Kruskal-Wallis test ($P = 0.03$) (Figure 8). Visiting the installation did not influence answers to the question about why scientists don't know all the species of microorganisms.

Table 2. Range of responses to the assessment item asking what percentage of microorganisms are harmful to humans before and after visiting *Tiny Enormous*.

Group	Low Value	High Value
Before	0.05%	100%
After	$3.3*10^{-4}$%	50%

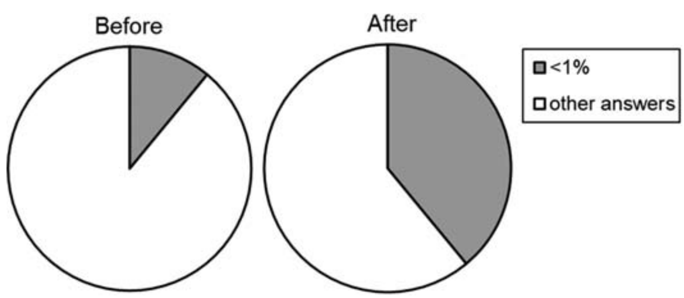

Figure 7. Percentage of respondents who answered that <1% of prokaryotes have been discovered, before and after visiting *Tiny Enormous*.

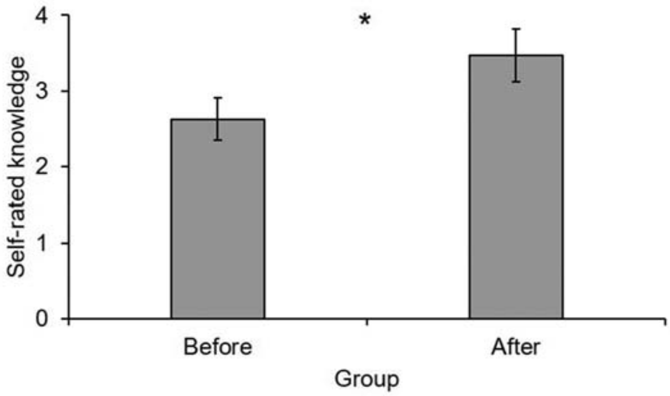

Figure 8. Respondents' mean (± SE) self-ratings of microbiological knowledge, on a 1–10 scale, before and after visiting *Tiny Enormous*. Asterisk indicates significant differences in self-ratings ($P < 0.05$).

○ Discussion

Our surveys revealed striking differences in the microbiological content knowledge and opinions between respondents who had visited the *Tiny Enormous* installation and those who had not. The respondents who had visited *Tiny Enormous* indicated higher self-ratings of microbiological knowledge, which were supported by the data (i.e., by more thorough and more accurate answers to our questions). For instance, visitors recognized more types of microorganisms and more roles played by microorganisms and were better able to recognize how little information is known. Most importantly, respondents who had visited the exhibition were much less likely to state the misconceptions about antibiotics and "superbugs" commonly held by the public – misconceptions that can be dangerous if they lead to patients misusing antibiotic prescriptions (Harrison & Svec, 1998; Hawkings et al., 2007; Nerlich & James, 2008).

We found similar responses between the two groups in only two items: why so little is known about microorganisms and self-rating how harmful microorganisms are. Our finding that respondents who had visited *Tiny Enormous* did not rate microbes as less harmful compared to respondents who had not visited the installation was unexpected, given that the running theme of the installation was that most microorganisms are harmless or even beneficial to humans. We surmise that the information in the installation about antibiotics, "superbugs," and epidemics led visitors to rate microorganisms as more dangerous despite information to the contrary. *Tiny Enormous* visitors were slightly more likely to state "causing disease" as one of the ways microorganisms affect humans, which further supports this explanation. Overall, *Tiny Enormous* had a strong short-term effect in correcting misconceptions and providing important information.

The mission of our exhibition is very timely. Other institutions have recently hosted exhibitions driven by similar purposes. For instance, the article "Invisible World Comes to Light" (Blackwell, 2017) describes a project led by two Harvard University scientists that used photography to engage and educate a broad audience about the ubiquity of microorganisms. The aim of their exhibition, entitled *The World in a Drop: Photographic Explorations of Microbial Life*, was to spark curiosity by presenting microbes in a beautiful way (Blackwell, 2017). Presented at the Harvard Museum of Natural History in fall 2017, it featured large-scale photographs of microorganisms.

We encourage other educators to develop their own activities that utilize microbe art or other biological artistic expressions. University art galleries are frequent sites for such installations (e.g., Blackwell, 2017) and are accessible to both high school and college students. When physical installations are not a possibility, educators can make use of online galleries (e.g., Gregory et al., 2009; Park, 2018; Racaniello, n.d.) that display dozens of images of microbe art illustrating the ubiquity and diversity of microorganisms. Educators can provide access to such galleries and then assess student learning in related topics. Reflective responses can indicate how art influences student knowledge and attitudes toward microorganisms. Other subdisciplines of biology – such as anatomy, zoology, botany, and entomology – are also frequently explored as subjects in art installations, which are ideal vehicles for illustrating elements of form and biodiversity.

○ Conclusions

Our installation, along with others, showed that art is an effective and accessible medium for educating and engaging both academic and public audiences. While *Tiny Enormous* educated its visitors about microorganisms, innovative artists and educators can explore virtually every discipline within biology and the natural sciences. We encourage others to consider the use of art galleries for outreach and education in traditional STEM disciplines. An integrative approach in which STEM education becomes STEAM education will help our students become more informed and intellectually diversified global citizens by visual means.

○ Acknowledgments

Funding was provided by a University of North Georgia Presidential Innovation Incentive Award. We thank Lauren Bradshaw (GA), Peggy Coots (KY), Terri Dilling (GA), Emily Glass (NY), Cynthia Kirchner (GA), Stacy Koffman (GA), Lucas Korte (KY), Cara McKinley (TN), Lennon Michalski (KY), Elizabeth Porcel (GA), Sara Schneckloth (SC), and Allyson Winter (GA) for contributing original pieces, and Anthony Pacheco, Brandon Fuller, and Tani Momin for assistance with swabbing gallery visitors. We are especially indebted to Victoria Cooke of the Roy C. Moore Gallery for assistance in developing, installing, and de-installing *Tiny Enormous*. We thank Swapna Bhat and Pamela Sachant for feedback on the manuscript. This study was approved by the University of Georgia Institutional Review Board (IRB No. 2017-131-C&U).

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Appendix: Information Posted in the Exhibition *Tiny Enormous*

Most microbes do not cause diseases. There are about 1400 organisms in total known to cause human diseases, only 100 of which are bacteria. That is only 1 in 300 of the ~30,000 bacteria known to science.

Bacterial cells can outnumber human cells in a single person's body. A single person can be a home to over 40 trillion bacterial cells, most of which are in the gut; in contrast, a single person contains slightly fewer human cells! These microbes can belong to 500–1000 species, although only a few species make up the vast majority of bacterial cells.

Virtually all known and predicted biodiversity is microbial. If all lineages of organisms are considered "branches" on a "tree of life," all multicellular, macroscopic organisms are one "twig." Almost everything else is bacteria.

Although only ~30,000 microbial species are known, scientists estimate that between one billion and one trillion species exist. In other words, our knowledge of total microbial diversity is essentially zero.

Why do we know so little about microbial life?

The reason we know so little about microbial life is that microorganisms are "invisible." We didn't know about their existence at all until two discoveries:

(1) microscopy, in the late 1600s, and

(2) the germ theory of disease, mostly developed in the 18th to 19th centuries.

But microscopes are limited to certain microbes, and most microbes don't cause disease.

We are just now learning more about microbes because we can search for and identify their DNA in the environment and use biochemical tests to learn about their unique metabolic activities.

As we sample more environments we discover more microbes; however, most environments have yet to be sampled. For instance, your body might contain numerous microbes that have evolved in unique ways during YOUR lifetime! Here, you can be sampled and discover the microbes that live on your body.

This wall represents small samples of microbes that have been sampled from you and others just like you. Can you find your cultures? How many microbes were cultured? How different are they than other samples?

Antibiotic resistant bacteria (ARB) are one of the most important health issues humanity faces. ARB evolves when microbes mutate in a way that allows them to resist antibiotics. Natural selection can increase the prevalence of these mutations in microbial populations. Microbes can evolve resistance to multiple antibiotics.

Antibiotics are prescribed to attempt to delay or manage the evolution of ARB traits. Selection for these traits occurs when antibiotics do not completely clear the most resistant microbial genotypes from a population. Be sure to always follow prescriptions, and be responsible in your use of antibiotics.