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Activity

Magnifying Minds: Exploring the Concepts of Size and Scale with a Public Mural and Integrated Activities

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ABSTRACT: In contemporary society, cultivating scientific literacy among the public is imperative for informed decision-making on matters influencing general well-being. Here, we report the multifaceted activity Magnifying Minds as a collaboration between artists and scientists to enhance scientific literacy through public art. Murals as a medium for science communication are deeply rooted in their historical significance and informal accessibility. Murals, as large-scale artworks, have the transformative power to reshape public spaces and engage diverse communities, extending beyond the confines of traditional art galleries and science museums. The impact of murals can be enhanced by coupling them with informal science education activities. This article summarizes Magnifying Minds by delving into the commissioning process for a scientifically themed public mural, the mural design itself that explores the concepts of size and scale, and educational activities inspired by the artwork. These activities seamlessly blend science and art, encompassing a mural puzzle, the use of magnifiers and optical microscopes, coloring of mural panels, and leaf rubbings. By showcasing Magnifying Minds, this article aims to guide similar initiatives in communities aspiring to adopt accessible approaches to science communication and education.

KEYWORDS: *General Public, Elementary/Middle School Science, High School/Introductory Chemistry, Public Understanding/Outreach, Applications of Chemistry, Art, Materials Science, Plant Biology*

■ INTRODUCTION

There is a critical need to develop an engaged and scientifically literate public to ensure that individuals outside the sphere of scientific research and higher education can make informed decisions about topics that affect their quality of life, economic prosperity, and security.[1−7] Many scientific literacy efforts within the United States occur within the context of K−12 education.[8−10] Also, TV programming such as NOVA by the Public Broadcasting Service and books such as *Napoleon's Buttons: How 17 Molecules Changed History* and *The Alchemy of Us: How Humans and Matter Transformed One Another* have been effective in bringing chemical concepts to adult populations.[11−14] STEAM education, the integration of science, technology, engineering, and mathematics (STEM) education with the arts, seeks to foster student creativity and build design principles and creative solutions.[15] STEAM initiatives often benefit STEM solutions and can be applied to efforts to enhance public literacy of science concepts by facilitating conversations. Yet, to achieve greater scientific literacy among the general public, there is also a need to break with conventional means of disseminating scientific content (e.g., classrooms, lectures, manuscripts) and meeting the public in informal environments with accessible content.[16]

To meet this goal, the Center for Single-Entity Nanochemistry and Nanocrystal Design (CSENND), sponsored by the National Science Foundation's Centers for Chemical Innovation Program, has initiated "Magnifying Minds". This activity aims to boost informal science communication through commissioning scientifically themed public murals in collaboration between a local artist and scientists and developing aligned educational art−science activities for use in the public space. Art has been used throughout history to convey stories and concepts.[17] People communicated through visual forms such as the Paleolithic paintings in the Cave of Altamira, Spain, and the hieroglyphs of Ancient Egypt.[18,19] In the present, the arts are increasingly a favored approach for science

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Figure 1. Illustration of the art-mediated learning of scientific concepts using a public mural alongside art−science activities in an informal setting.

communication in both formal and informal settings, catering to the general public and specific interest groups alike.[20−23]

Murals allow for large-scale artwork that can have a significant impact on a space, transforming the environment, whether they appear on the sides of buildings, on garden walls, within libraries, or more. Murals in public spaces can engage a broad audience, bringing art to underserved communities and those that might not visit traditional art galleries or science museums. Murals are also accessible and, in the era of social media, are great spots for engagement. Beyond their aesthetic appeal and accessibility, murals can convey history and stories. For example, Mexican artist Diego Rivera used three large walls within a grand stairwell of the National Palace in Mexico City to depict the historical narrative of Mexico,[24] bringing events like the Spanish Conquest, the fight for independence from Spain, the Mexican−American war, and the Mexican Revolution to the public.

Murals also can communicate scientific concepts. For example, the University of Wisconsin—Madison has a program called "Science to Street Art" wherein different science murals are created.[25] Notable examples include a mural highlighting the carbon cycle, revealing hidden natural cycles, and one featuring astrophysics, showcasing the 10 most abundant atoms in the universe with their accurate electronic configurations. Another example is the ART±BIO Collaborative, where local artists, scientists, naturalists, and educators came together and created murals on biological concepts, natural history, research, habitats, environments, and study organisms.[26] We anticipate that science−art partnerships of this nature can be enhanced through integrated educational activities, as described herein with Magnifying Minds.

The learning objective of Magnifying Minds is to enhance public understanding of size and scale and their impact on modern life. This emphasis comes from CSENND's scientific focus on nanoscience, for which excellent educational activities have been reported,[27−29] but also because size and scale are critically important concepts more broadly as well. Project 2061 by the American Association for the Advance of Science identified scale as one of four themes that run throughout STEM and transcend disciplinary boundaries, being essential understanding for a scientifically literate public, with the 2013 Next Generation Science Standards including "scale, proportion, and quantity" as part of the U.S. national education standards.[6,7,30] Given the importance of scale to modern life, there has been substantial research directed to students' understanding of scale and into the efficacy of different instructional approaches.[31−39] This research has often focused understanding students' conceptualization of scale in the context of time (e.g., by having students rank events in geologic time using a Likert-type scale)[34] or linear distances (e.g., by having students assess and sort the perceived sizes of objects),[31] although conceptualization of mass, volume, and other spatial−temporal relationships is important and is being studied. In relation to the Magnifying Minds project, a study by Trate et al. found through classwide studies of students in an introductory college chemistry course that, "students seemed to recognize a distinct size difference between the 'atomic' and 'microscopic' scales, [but] students often failed to differentiate correctly between objects falling into those categories."[40] They also noted that, "students infrequently selected nonvisible objects as anchor points or selected only generic, nonvisible anchor points" to reference objects such as "too small to be seen." They emphasized that these results indicate that novice college chemistry students do not demonstrate a high level of scientific literacy with regard to scale. Given this finding and that only ~50% of working-age adults complete postsecondary degrees within the United States, opportunities to engage the public in discussions of scale are critically needed.[41] As outlined on the Magnifying Minds website, "We live in a world where both big and small numbers are commonly cited to explain challenging concepts, and understanding the scale of everyday objects is important to make informed decisions. Whether it be the selection of an appropriate filter to remove virus particles from a classroom or the decision to leave a coastal region as a hurricane approaches, an understanding of size and scale can be useful."[42]

Here, we report Magnifying Minds as a large, multifaceted activity (Figure 1). We start by describing the commissioning process for the public mural so that others may initiate such science−art partnerships in their communities. Then, the mural design is revealed, followed by learning objectives and implementation guides for several educational activities inspired by the mural. These activities, by design, fuse science with art and include (i) a mural puzzle exploring scale, (ii) use of magnifiers and optical microscopes, (iii) coloring of mural panels, and (iv) leaf rubbings.

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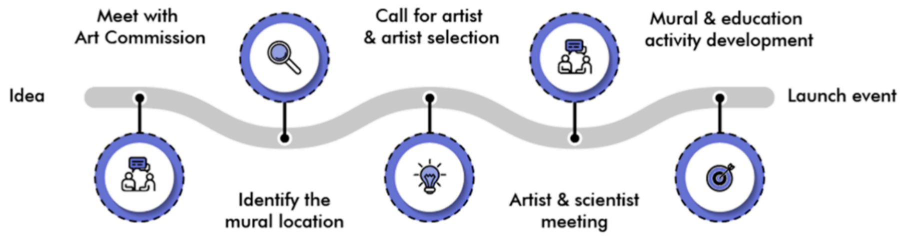

Figure 2. Flow diagram describing the steps in Magnifying Minds, from conception to mural launch event.

Figure 3. Photographs of the mural providing a (a) full panoramic view of the mural and (b−i) different sections of the mural.

■ COMMISSIONING THE MURAL

Commissioning art in public spaces requires engagement with the surrounding community, and there will likely be some variations in the steps involved and the level of support based on one's environment. The first public mural for Magnifying Minds was commissioned in Bloomington, IN, and involved collaboration between the CSENND scientists, the Bloomington Arts Commission,[43] a local artist, a local property owner, and Bloomington's WonderLab Museum of Science, Health, and Technology.[44] The steps are summarized in Figure 2 but began with CSENND leadership discussing the project goals with leadership at the Bloomington Arts Commission and their public art subcommittee. Most cities within the United States will have similar commissions/committees/offices that seek to promote the arts and encourage community appreciation for and engagement with the arts. In our case, the Bloomington Arts Commission was well-positioned to oversee the public art aspects of this project. They worked with local property owners to identify the wall for the mural, an alley adjacent to WonderLab and in the heart of the town's commercial district. They led a call for artists, wherein artists submitted mural designs that sought to align with the project's theme of size and scale. Their granting committee also reviewed the artist applications. Through these steps, CSENND leadership provided feedback on potential mural locations, provided scientific learning objectives for the mural that were included with the call for artists, and provided feedback on the submitted mural designs. These discussions were viewed as critical so that the commissioned piece would ultimately align with CSENND's goals in terms of informal science communication.

Local artist Erin Tobey[45] was selected to create the mural based on her application, wherein she wrote, "I propose a mural that shows a journey through the microscope to explore inside plants and how cellulose nanocrystals can be turned into useful technologies to enrich human and environmental health. The half of the mural in this rendering represents a viewer and a tulip poplar leaf, moving into its microscopic structure, the cells, the fibrils, extending all the way to the molecules. The unfinished southern half of the wall would come back up from the nanoscale into technological applications that ends back up in a child-scale world on the southern end of the mural near

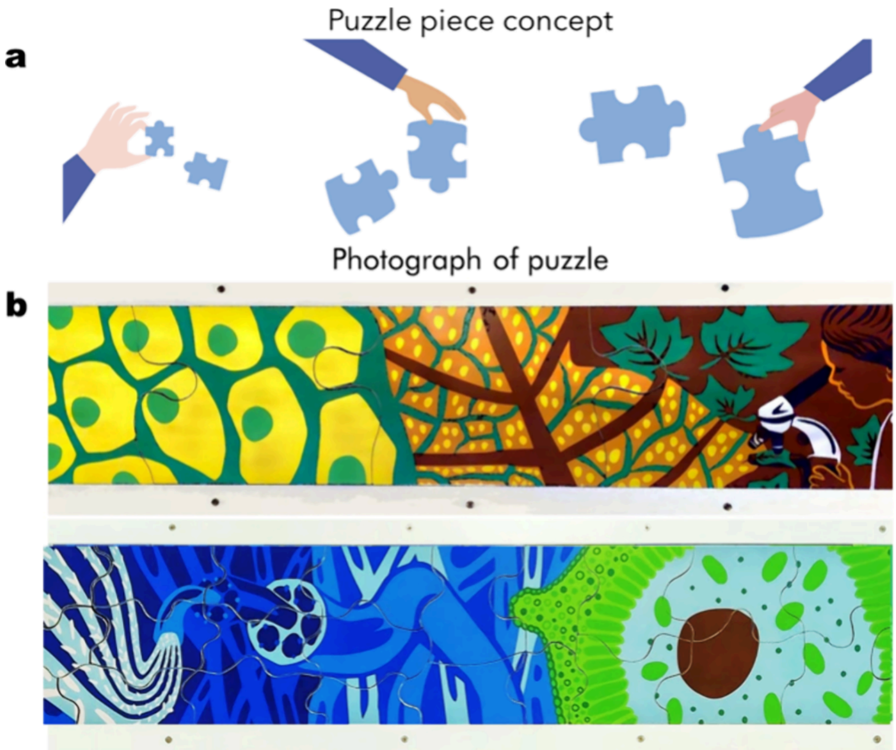

Figure 4. (a) Depiction of the puzzle piece concept. (b) Photograph of the puzzle pieces.

WonderLab." Prior to painting, members of CSENND and the Bloomington Arts Commission met with the artist to review the mural design, providing minor feedback with regard to the design. This meeting, we believe, is a critical feature of such collaborations. In our case, the meeting provided an opportunity to enhance the scientific content of the mural as we provided microscopy images of cellulose nanocrystals as inspiration to the artist. Also, a student member of CSENND began brainstorming age-appropriate educational activities inspired by the design for a mural launch event to be hosted at WonderLab and leveraged the creativity from the artist in the development of activities. The Bloomington Arts Commission then coordinated all aspects of mural painting (e.g., wall preparation, traffic diversion) and a media-focused mural launch event upon mural completion.

■ MURAL DESIGN AND LAUNCH

Figure 3a shows a panoramic photograph of the mural, and Figure 3b−i includes photographs of mural portions given its length of half a city block. The mural design follows in the tradition of comics or sequential art, which seeks to present a story sequentially. The mural can be read from either direction. Approaching from the left (Figure 3b), a macroscopic world is depicted with a hand holding a dandelion, which breaks down to its smaller seeds being transported in the wind. Further down, maple tree seeds transition to a tree. From this direction, the mural is geared toward young children and introduces the idea that larger objects can be broken down into or created from smaller objects. Approaching from the right (Figure 3i), the mural depicts a person holding a microscope and looking at a leaf, which then transitions into a microscopic journey through a leaf and its structure of cells and nanoscale crystals of cellulose at increasing magnifications. This journey is geared toward older children and adults. The blue portion of the mural (Figure 3i) reveals cellulose nanocrystals, colored in white, which can be used to create filters that remove pollutants from water. This connection between the nanoscopic world and technological advances is depicted abstractly with the blue waves that provide water to the mural's tree, nourishing the macroscopic world.

As discussed in the subsequent section, educational activities were developed for use at the mural site during its launch and at subsequent neighborhood events. However, given that most of the engagement with the mural will happen outside of those events, a QR code is available at the mural that directs viewers to the Magnifying Minds website.[42] We believe that this sign is essential given that some aspects of the mural are abstractly depicted, with the entire concept captured with the artist's statement. We also believe that this sign is essential because the mural itself does not contain information about the actual size of items or the magnification that would allow humans to see them. Their addition to the mural would undercut the aesthetic appeal of the mural and independence of the artist. Thus, the website provides a rendition of the mural's right side, along with the approximate scale of the different segments (denoted in meters down to nanometers, with inches also provided for reference to those unfamiliar with the metric system) as well as magnifications required to view. A short description about the history of units (beginning with the Egyptian and Mesopotamian cubit and the need for standard units) and units of length measurements accompanies this information, along with the sizes of well-known objects for reference (e.g., atoms, DNA, viruses, red blood cells, human hair, an ant, a sunflower seed, and a leaf). Examples of how one can measure the lengths of objects and links to educational worksheets where individuals can practice measurements are also provided. Finally, a video is provided to (1) introduce the audience to various measurement units, (2) provide understanding of how optical and electron microscopes work and

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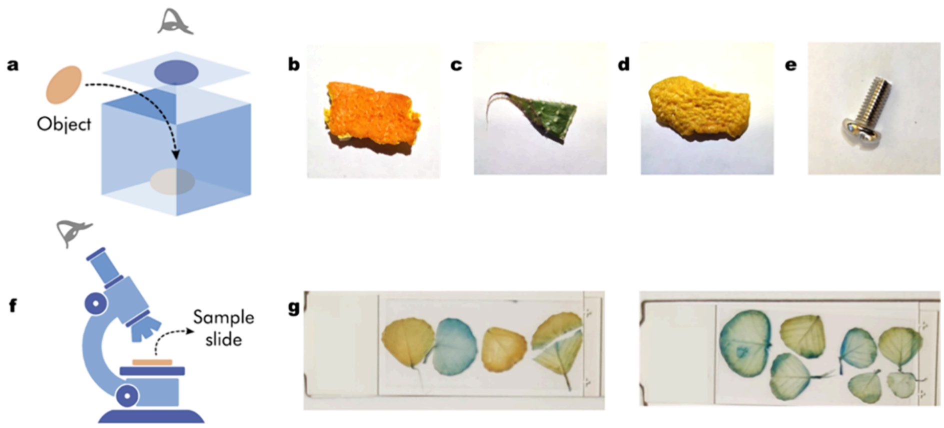

Figure 5. (a) Schematic of a cube or box magnifier along with (b−e) photographs of objects. (f) Schematic of optical microscope along with (g) photographs of the plant slides.

(3) how they are useful for seeing at different magnifications, and (4) learn how magnification of an image leads to additional information through a practical example. The educational content of the Magnifying Minds website was created by graduate students associated with CSENND.

■ MURAL-INSPIRED EDUCATIONAL ACTIVITIES

To enhance the learning associated with the mural, several educational activities were created by CSENND students for the media-focused launch event held at the mural location. Given the uncertainty of weather in Bloomington, IN, at the time of the mural launch, the educational activities were hosted within WonderLab. Importantly, they waived their entry fee for the afternoon so that anyone could engage with the educational activities inside immediately after the ribbon cutting, consistent with the value of public art being accessible to all. These problem-solving actions highlight the community nature of this science−art partnership as well as the importance of selecting an appropriate mural location that will facilitate other means of engagement. Outlined herein we describe the four activities developed and implemented at the launch event to enhance public understanding of size and scale and their impact on modern life. An important consideration when developing these activities was the anticipated demographics of the attendees, with WonderLab typically hosting young children (5−10 years) and their parents/guardians.

A Mural Puzzle Exploring Scale

There are different types of puzzles (e.g., jigsaw puzzles, crossword puzzles) that are both fun and effective learning tools in various disciplines.[46,47] Puzzle-based learning has existed for over 60 years in education and has the edge of being more interactive and learner-centered compared to conventional teaching.[48] With these learning benefits in mind, we had a large jigsaw puzzle created of the same artwork that is depicted in the mural. The puzzle was printed on an aluminum composite sheet and custom cut (along with a supporting frame) at Indiana University's Mechanical Instrument Services. Unlike a typical puzzle where the pieces are of similar size, this puzzle was cut so that the pieces on the right side were largest and they gradually decreased to the left, corresponding to the microscopic journey to higher magnification and smaller features (Figure 4). This design provides an opportunity to build understanding that there is a microscopic and nanoscopic world. That is, participants should be able to describe what a magnifier does and how a magnified image differs from what they observe unaided.

Implementation of this activity is straightforward, requiring only a space for the puzzle and an instructor to facilitate discussion. While a picture of the mural could have been provided to guide placement of the puzzle pieces (and would be at the mural location), we opted for a discussion-based approach to puzzle solving, where participants were asked to select a puzzle piece and the instructor followed with questions such as, "Is a person larger or smaller than a leaf?" "Is a cell larger or smaller than a leaf?" "Is a nucleus smaller or larger than a cell?" The puzzle pieces could then be placed in rank order with this information to facilitate placement while growing knowledge of the relative sizes of different items. We note that if older children or parents are engaged in the puzzle solving, more advanced questions and discussion topics can be implemented, including those focused on the actual sizes of objects, the magnification required to view different objects, and even the different types of microscopes (e.g., optical versus electron microscopes) required to view objects of different sizes. Additionally, the ranking of objects by relative size can be expanded to include objects not depicted in the mural (e.g., atoms, molecules, nanoparticles, viruses), allowing for size connections between other objects to be made.

Use of Magnifiers and Optical Microscopes

From the right, the mural begins with a young person looking through a microscope that some viewers of the mural may even identify with.[49,50] Thus, we sought to create this depiction with the opportunity for participants to use optical microscopes and other magnifiers. There are several learning objectives with this activity. First, just as with the mural puzzle, participants should be able to describe the function of the magnifier and articulate the distinctions between a magnified image and their unaided observations. Second, participants become familiar with the scientific practice of observation, and curiosity is fostered through seeing the unseen. Third, participants should be able to describe and distinguish features of objects that can be observed in greater detail with magnification.

For implementation, 10 snap-on magnifier cubes or box magnifiers, two magnifying glasses, and two optical microscopes were available. Note that a power source is required for many optical microscopes, but this activity could be modified to use plug-in magnifiers to cell phones and even Foldscopes, inexpensive foldable microscopes mostly made of paper.[51]

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Objects for imaging with the box magnifiers and magnifying glasses (Figure 5a−e, Table S1, Figure S1) were available, as were prepared slides for the optical microscope (Figure 5f,g). Given the mural's depiction of imaging a leaf, we consulted with biologists at Indiana University who provided slides showing an infection of a common legume plant, *Medicago truncatula*, with a hemibiotrophic fungus, *Colletotrichum destructivum*; however, a variety of other prepared slides are available commercially and can be used as well (Figures S2 and S3 and Supporting Note 1).[52−55] For example, slides of butterfly wings or beetle wing cases can be imaged and provide an opportunity to discuss the origin of structural color, while slides of different polymers (e.g., cellulose as depicted in the mural) can be imaged and provide an opportunity to discuss their morphological and dynamic properties.[56−58] Both are appropriate for older audiences.

Instructors demonstrated to participants how to use the various magnifiers and assisted them in changing the magnifications of the optical microscopes. To build observation skills and infuse an artistic element, each participant was provided with drawing materials and a mural-inspired drawing page to record their observations. Instructors would periodically check in with participants and field questions. Knowledge of the microscopic features of the prepared slides by instructors is essential to field questions, which typically focused on the identity and function of various features.

Coloring Mural Panels

For this activity, the mural's artist provided our team with coloring sheets depicting different portions of the mural, and crayons and color pencils were available (Figure S4). Instructors would ask participants why they selected a particular coloring sheet and use that information as a springboard for discussion about the scientific content of the image, addressing general inquiries. In implementation, we found that many were simply interested in taking the coloring sheets home for later completion, so QR codes that link to the mural's website will be printed on the back of the sheets moving forward.

Leaf Rubbing

As a final science−art activity, we provided materials for leaf rubbing. This creative endeavor involves making art through the impressions obtained from leaves and provides an opportunity for participants to learn about the parts of a leaf. Leaf rubbing allows participants to explore the natural patterns and textures found in leaves, creating a connection between art and nature. It is a simple yet effective way to appreciate the beauty of plant life and create unique artworks that showcase the intricate details of leaves.

To implement this activity, a variety of leaves were collected, ensuring they had distinct vein patterns and textures. Then, the leaves were placed underside up on a firm and flat surface and secured in place with tape. Alternatively, they could be held in place with one's hands. Then, a sheet of paper was placed over a leaf, making sure it covered the entire leaf. An unwrapped crayon or pencil could then be gently rubbed over the paper covering the leaf to reveal the leaf's texture. Participants could experiment with arranging multiple leaves under the paper and creating overlapping designs for more intricate compositions. Figure 6 shows the steps of leaf rubbing art in an easy manner. The instructor can facilitate discussion about features revealed in the rubbings, such as the vein, midrib, rib, and petiole.

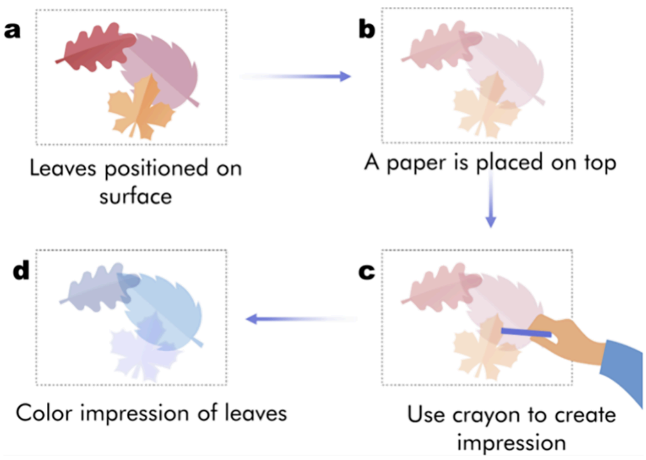

Figure 6. Schematic depicting the process for leaf rubbing art.

HAZARDS

None of the materials used in the events are hazardous. They can be safely used in any environment.

CONCLUSION

The mural launch event was well-attended, with high engagement at both the ribbon cutting and indoor mural-inspired educational activities. However, the informal setting with young children and families made formal assessment inappropriate. We can report that adults sought out CSENND members and expressed curiosity about how this art−science partnership was initiated and connected to their research. In this way, the mural was effective at getting the conversation started about the science. Also, many attendees took photos of themselves with the mural, with children being especially attracted to the art piece. When indoors, the children were similarly drawn to the mural-inspired educational activities, which we attribute, in part, to familiarity with art supplies that diminished the barrier for engagement. The hands-on nature of the activities, coupled with the production of drawings or colorings and inquiry-guided discussions, provided an experiential learning process.

As a major goal of Magnifying Minds is to meet the public with scientific content where they are, in informal environments, these mural-inspired activities will be used again by CSENND members attending the neighborhood's summer block party and other community events near the mural site. We are also expanding our mural-inspired activities to highlight the nanotechnology applications of cellulose nanocrystals to water purification. A long-term goal is to leverage the CSENND network to provide activities to researchers for use in other communities and ultimately form a network of Magnifying Minds science−art partnerships for the commissioning of additional murals and creation of mural-inspired educational activities.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.4c00111.

Photographs of additional objects used for box or cube magnifiers and magnifying glasses; colors and surface textures of objects used for box magnifiers and magnifying glasses; slide preparation, process of

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infection of *Medicago* leaves with *Colletotrichum* fungus; process of staining infected leaves; slide preparation with view through the microscope; photograph of coloring sheets from the mural design (PDF)

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Notes

The authors declare no competing financial interest.

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