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The feel of inclusivity

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Collaboration between diverse groups with different perspectives promotes scientific discovery. To enhance these partnerships and facilitate communication, innovative advances in universal design are essential.

Do you know what an atomic orbital looks like? Can you draw a picture of chemical resonance? Can you sketch the intermediates that occur during a chemical reaction? A college student who has taken General Chemistry might enthusiastically cartoon s, p, d, and f orbitals for electrons. They might tell you that they were taught to represent chemical resonance as multiple Lewis structures. If they have taken Organic Chemistry, then they may illustrate a chemical reaction with arrow-pushing diagrams. Despite being able to construct pictures, however, they have never actually seen any of these things directly with their own eyes. No one has. We can only infer what they look like from experimental data and calculations.

Professors help students develop an understanding of orbitals and chemical reactions by rendering images on an *x-y-z* coordinate system and by using various tools such as interactive digital models and videos. Although no one can observe them directly, teaching students to “see” atoms and molecules with the aforementioned techniques excludes the nearly 40 million people worldwide who have blindness (1). The exclusion of students with blindness is not just limited to atomic orbitals, resonance, and molecular reactions. The “visualization” of scientific concepts is systematic in both introductory and advanced courses and leads to considerable educational barriers for students with blindness or low vision. A standard biochemistry textbook, for instance, contains over 1000 illustrations, many of which depict molecular structures (2). Without an understanding of basic chemical principles, it is challenging for students to pursue advanced careers in adjacent fields or to engage in scientific research.

THE NEED FOR UNIVERSAL DESIGN

The blind individuals who do go on to earn graduate degrees in science and perform research generally rely on braille, tactile graphics, tactile models, text-to-audio translators, and other assistive technologies (3, 4). As an example, the Picture in a Flash Tactile Graphic Maker converts custom 2D imagery into tactile forms (also referred to as “swell forms”) that can be perceived by touch (5). When special paper is heated, foam-like swelling occurs in regions where there is black ink or toner. A drawback of swell-form technologies is that they are unable to topologically differentiate important details in scientific images and data, such as the noise region of a mass spectrum (6). An alternative to handheld graphics is candy-like molecular models that can be sensed by the tongue and lips, which were originally developed by Shaw and his team (7). The advantage of the latter is that the mouth has finer tactile sensors than the hand. Anyone who has ever had a small chip in a molar tooth can relate—minor surface irregularities can be sensed with the tongue but not the fingers.

The term “universal design” describes a framework for creating a physical, learning, and work environment that is equally usable by everyone, irrespective of their age, size, or diverse abilities (8). Current graphics and assistive technologies in the chemical sciences fall short of providing a single high-resolution format that can be used by both individuals with blindness and individuals with sight. In a classroom setting, this lack of a universal design format complicates the interactions between students who must learn from different sources of information. In a research

laboratory, it limits collaboration because scientists with blindness and scientists with vision cannot discuss or evaluate data in an identical format.

LITHOPHANES REINVENTED

In the mid-19th century, interest in a form of art known as lithophanes took hold of Europe (9). At the time, lithophanes were made by etching a 3D design into a thin sheet of translucent porcelain. When illuminated from behind, the varying depths of the porcelain influence light transmission. Thinner regions appear brighter and thicker regions appear darker, thereby creating image contrast through topology. Although their popularity diminished when photography was invented, the recent advent of 3D printers has led to a resurgence of excitement for lithophanes. They can now be created by using relatively inexpensive 3D printers and resin that costs less than 50 cents an image.

A quick Google Image search will reveal homemade lithophanes used for various artistic purposes ranging from lampshades to Christmas tree ornaments and keychains. There are even step-by-step protocols for creating lithophane business cards. Writing in this issue of *Science Advances*, Koone *et al.* (6) introduce yet another function for lithophanes. Beyond satisfying the latest craze in home decor, Koone *et al.* suggest that lithophanes may be able to help address a longstanding problem that has made it challenging for individuals with blindness to learn chemistry and exchange research data.

The insightful discovery made by Koone *et al.* is that lithophanes not only provide visual images that can be viewed by persons with sight but also simultaneously enable graphics to be encoded spatially so that individuals with blindness can perceive the same information (Fig. 1). The researchers demonstrate that lithophanes produce tactile graphics with better accuracy and resolution

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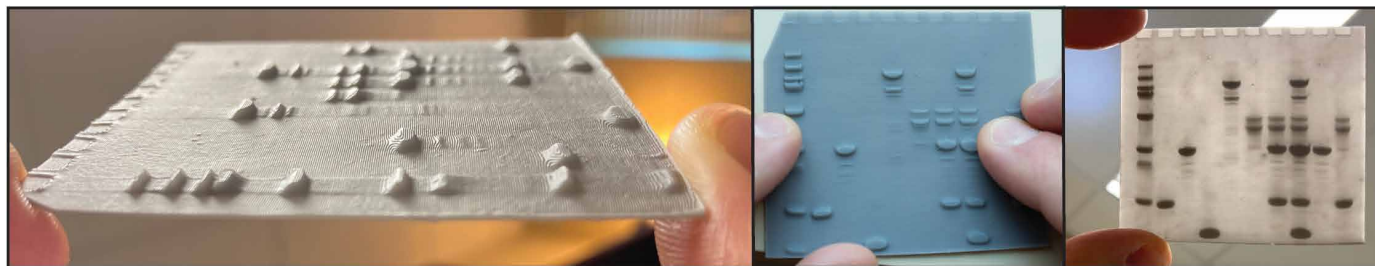


Fig. 1. An SDS-PAGE data or a “gel” transformed into a thin, translucent tactile graphic known as a lithophane by using a 3D printer. Left and center: The lithophane projects tactile data quantitatively (darker band = taller protrusion) that can be visualized and interpreted by touch. Right: The exact same lithophane from left and center held up to an ambient light source (here, a ceiling light) and visualized conventionally with eyesight, as on a computer screen or laboratory white light box. SDS-PAGE is a widely used technique in the biological sciences, but its data are inaccessible to persons with blindness. Photo credits: Elizabeth Shaw and Bryan Shaw.

than the Picture in a Flash technology. In fact, the investigators claim that the millimeter scale of signal protrusions in 3D-printed lithophanes can approach the maximum resolution of the human eye—meaning that any information from the lithophane that is seen can also be perceived by touch. Unlike other tactile graphics, lithophanes have a one-to-one correspondence between the intensity of light observed and the thickness of the surface, thereby making them well suited for use by both people with vision and people with blindness.

PUTTING LITHOPHANES TO THE TEST

Koone *et al.* created lithophane forms of textbook illustrations, gel electropherograms, micrographs, electronic spectroscopy data, and mass spectrometry data. The mass spectrometry data were particularly intriguing because they blew up a region of spectral noise, which is not typically perceptible through other forms of tactile graphics. The ability to interpret each lithophane by visual inspection or tactile sensation was tested in three independent groups: participants with vision, participants with blindness, and participants with vision who were blindfolded. Each of the 360 participants answered questions such as “What is the m/z value of the most intense peak in the spectrum?”. For most of the questions asked, tactile accuracy by participants

with blindness was equal or better than visual interpretation by individuals with sight. The results suggest that lithophanes are well suited as a tool for universal design.

PROMOTING INCLUSION AND COLLABORATION

Oral presentations, either at regular group meetings within a research laboratory or at conferences, are a primary medium by which scientists interact. Most often, the presentations are aided by a combination of computer slides and board illustrations. Unfortunately, neither of these data formats are accessible to investigators with blindness or low vision. Lithophanes offer comparable resolution and interpretation accuracy compared to digital images. Moreover, although mass production was once limited to just a few factories in Europe, lithophanes can now be inexpensively created by anyone with access to a standard 3D printer. It is therefore compelling to consider converting each PowerPoint slide from a presentation into a lithophane, so that the scientists in the audience can hold the graphics in their hands like a deck of playing cards. By moving toward such a universal data format, it will promote inclusivity, dialogue, and collaboration between diverse groups of researchers who may have different perspectives, which is key to advancing scientific discovery.

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