Using Tactile Learning Aids for Students with Visual Impairments in a First-Semester Organic Chemistry Course

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It has been suggested that visualization is important to learning organic chemistry *(1),* and yet it presents an imposing challenge for many students. For example, students need to be able to visualize the different shapes of atomic and hybridized orbitals to understand the implications that these shapes have on the structures and properties of molecules. In reaction chemistry, students need to be able to understand the visual cues provided by chemical structural formulas in order to transform molecules into their various functional groups and to build new molecules. Additionally, many of the comparative assessments that students are asked to make throughout the course depend upon visual differences between two or more illustrations (e.g., reaction energetics via potential energy diagrams).

For a student who has low vision, learning organic chemistry may be a particular challenge because the student does not have the advantage of seeing the illustration while it is being described. Even in textbooks that have been translated into audio form, figures are only described at the end of the page. Verbal or written analogies may make sense to a person with sight when accompanied by an illustration, yet may confuse a blind person because of descriptive inaccuracies. Take, for example, the description of the shape of a p orbital. In both general and organic chemistry textbooks, various analogies have been used to describe the shape of this orbital (Figure 1A). Perhaps the most prevalent wording in use *(2)* is to describe the p orbital as "dumbbell-shaped" (Figure 1B). One organic chemistry textbook *(3)* compares the lobes of a p orbital to a doorknob (Figure 1C). A sighted person can easily distill the analogy that a textbook or instructor is trying to make between these objects and a p orbital. However, a student who has low vision may have difficulty doing so, especially if his or her experience with said objects is nonexistent or based on a tactile correlation of the object that is at odds with what is being described.

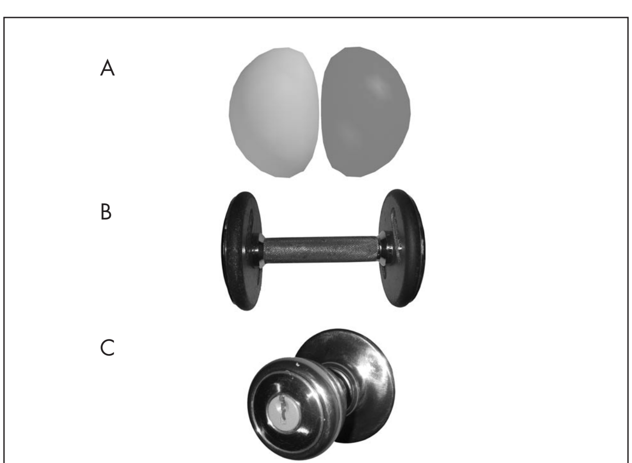


Figure 1. Images of (A) a p orbital *(4)*; (B) a dumbbell; and (C) a doorknob. Both B and C are objects commonly used to reference a p orbital's geometry.

This paper is based on the experiences of the two coauthors—a student who is blind and her instructor—from the first semester of a two-semester organic chemistry course taught at Scripps College. Teaching chemistry to students who have low vision has been reported on periodically in this *Journal (4).* The majority of these papers have focused on making laboratory activities accessible to students who have low vision. Few specifically address the visualization challenges that organic chemistry presents *(5).* Thus, we focused on finding effective and economical methods of representing graphics common to organic chemistry in a tactile manner. Our account of these efforts and the two techniques that resulted are described below.

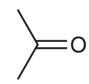
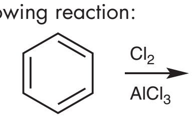
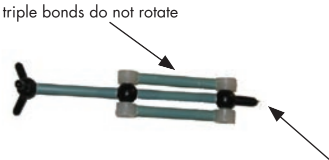
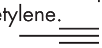
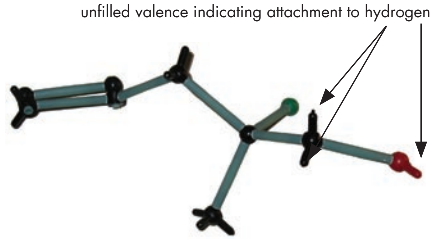
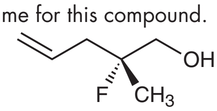
Strategies To Produce and Use Tactile Learning Aids

Our first approach was to utilize a thermal paper expansion machine, a device that produces tactile graphics *(6).* It works by causing the special paper used with it to become raised in places where the ink is dark. Unfortunately, the machine we selected did not consistently produce results good enough for the graphics we chose to develop. Specifically, the elemental symbols, chemical structures, and illustrations of orbitals usually could not be distinguished by the student. Attempts at having the machine produce Braille were also unsuccessful, and trials that did produce usable product did not successfully convey the three dimensional nature of the chemical objects.

Our remedy to the problem of representing molecules was to use traditional molecular models. Most students of organic chemistry use molecular models as an aid to translate a two-dimensional image on a page into a three-dimensional object. We sought a model set that would effectively convey the details of bond type (i.e., single, double, and triple bonds), bond angles, and molecular conformation, *as well as* act as the main mode of communicating molecular structure for both the student and the professor. We found that the orbit molecular building system from Indigo Instruments *(7)* best met these requirements because this system had:

1. Pieces that were small enough to be transportable, yet large enough to convey structural information in a tactile manner
2. Pieces that allowed for conformational flexibility
3. Pieces that mimicked the way double and triple bonds are drawn on paper while also preventing bond rotation about them
4. Adaptability for representing molecules in much the same way that line-angle drawings represent molecular structure

Table 1. Tactile Molecular Models and Corresponding Examples of Their Use with Students Who Have Low Vision

Compound Name	Model Shaped and Handed to Student	Traditional Representation	Verbal Instructions Provided
A. Acetone		Indicate the hybridization for the oxygen and each of the carbon atoms in the molecule below: 	Indicate the hybridization for the oxygen and each of the carbon atoms in the molecule provided.
B. Benzene		Predict the product of the following reaction: 	The compound you are given is reacted with molecular chlorine and aluminum trichloride. Predict the product of this reaction.
C. Propyne	double and triple bonds do not rotate 	Show how you would synthesize this compound from acetylene. 	Describe how you would synthesize this compound from acetylene.
D. (*R*)-2-fluoro-2-methylpent-4-en-1-ol	unfilled valence indicating attachment to hydrogen 	Provide an IUPAC or common name for this compound. 	Provide an IUPAC or common name for this compound.

Examples of using the orbit molecular building system are provided in Table 1. Like line-angle drawings, the overarching rule that allowed the models to be used was that atoms with unfilled valences (the nubs typically attached to the next atom using a hollow tube) were assumed to be attached to hydrogen. Used in this manner, every single problem in the text or on exams that required molecular representation could be modeled. This allowed the coauthors to communicate with each other in roughly the same manner that was being done between the instructor and the sighted students in the class. Below are descriptions of how several problem types were handled.

Predicting the Products of Reactions (Table 1, Row B)

The student was handed a model of the reactant and told what set of reagents it was treated with. The student would subsequently identify the type of functional group present in the model and describe what it would be transformed into, indicating regiochemistry and stereochemistry if applicable.

Synthesis (Table 1, Row C)

The student was given a model and directed to describe how it could be synthesized. In some cases, a model of the starting material is also provided.

Nomenclature Questions (Table 1, Row D)

A model would be built and handed to the student who would then be responsible for naming the molecule. Most elements could be determined by their valency. Notable exceptions to these include halogens and alkoxy oxygens. In these cases, the student was told what element was being represented. A chemical name was read, and the student was asked to build the structure using the model kit.

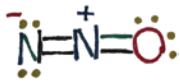
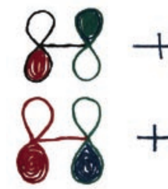
Mechanism

The student was given two molecular models and told the reagents used to transform one into the other. The student was then asked to describe the mechanism of the reaction using her fingers to indicate flow of electrons. After each step, a new model was constructed and given to the student.

Modeling with Wax-Covered String Manipulatives

The molecular models allowed for effective communication of molecular structure between instructor and student. However, visual-to-tactile translations were also required in other areas and with other question types. Because it was not practical to find three-dimensional objects to represent every chemical entity encountered in the semester, we used a commercial product known as Wikki Stix. Wikki Stix are a pliable combination of wax and yarn manufactured by Omnicor, Inc. *(8).* The product has long been used as an educational tool for people who have low vision, however to our knowledge, its use in the college chemistry curriculum has not been reported in the literature. When used on a flat surface, the stringy material provides a tactile sensation similar to the output of thermal paper enhancers. Unlike tactile graphics on thermal paper, Wikki Stix are inexpensive, reusable, and (most importantly) manipulable. The latter quality allowed

Table 2. Examples of Wikki Stix Shaped To Illustrate Chemical Concepts in a Tactile Format

	Tactile Graphic Presented to Student	Instructions Given	Graphic Created by Student in Response
A.		Provide a resonance structure for this compound. Indicate formal charges and all lone pairs of electrons in your answer.	
B. (The student provided both of the representations shown in B.)		Provide the pi MO diagram for ethylene and show what happens when ethylene absorbs UV light.	
C.		For the reaction energy diagram provided, label the reactants, products, transition states, and intermediates. Indicate quantities that represent the activation energy and enthalpy of reaction. Finally, determine whether the reaction is overall exothermic or endothermic.	None. The student points out each of the requested items to the instructor.

the instructor to set up a tactile "illustration" or question and allowed the student to ask or answer questions by manually changing parts of the illustration. Examples of the utility of the Wikki Stix, three of which are shown in Table 2, include, but are not limited to, discussing Lewis and resonance structures; orbital shapes and arrangements; molecular orbital theory; states of matter; and potential and reaction energy diagrams.

Guidelines and suggestions for approaching logistical issues that students who have low vision may encounter in a chemistry course (such as administering exams, obtaining textbooks in Braille or audio format, note taking, etc.) have already been described in this *Journal (4a, g)*. In addition to these techniques, we found it useful for the student to meet with the instructor at least once per week to go over questions and key points using the orbit molecular models and the Wikki Stix. Although the preassembly and the use of tactile models was time consuming, in this manner, nearly[1] every graphic encountered in the course was amenable to tactile translation.

Summary

Two new approaches for using commercially available products as tactile learning aids in organic chemistry have been described. Their use, in combination with existing techniques and technologies, have the potential to make organic chemistry more accessible to students who have low vision.

Acknowledgments

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Note

1. Electrostatic potential maps on electron density surfaces were difficult to translate into a tactile image.

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