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Activity

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Exploring Scientific Ideas in Informal Settings: Activities for Individuals with Visual Impairments

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Supporting Information

ABSTRACT: Four new modules for the scientific education of individuals with visual disabilities are reported. Designed for informal settings, the modules are safe and inexpensive and last 10−15 min each. The module entitled The Sound and Feel of Data represents axes and data points with pipe cleaners and coins, respectively, allowing for a discussion of data presentation and trends without reliance on visual signals. The Conductivity of Materials module tactilely introduces concepts of electron flow in metallic, semiconducting, and insulating materials using marbles, followed by a sound volume representation of the conductivity of everyday objects. The Optical Lenses module uses rope segments secured to a corkboard to trace tactile ray diagrams representing the concept of focusing, diverging, and aberration in optical lenses. Finally, the Chemistry and Physics of Heat module uses the dissolution of ammonium nitrate and sodium sulfate in sealed plastic tubes as well as the crystallization of sodium acetate to describe endothermic and exothermic processes. The modules were tested during an event attended by 38 participants with visual impairments; answers to learning assessment questions as well as pre- and post-module surveys suggest that we were successful at introducing scientific concepts and generating interest in science. This work provides new ways to introduce science that are applicable to all learners, visually impaired or not.

KEYWORDS: *General Public, High School/Introductory Chemistry, Public Understanding/Outreach, Hands-On Learning/Manipulatives, Precipitation/Solubility, Aqueous Solution Chemistry, Materials Science, Solids, Physical Chemistry*

INTRODUCTION

Blindness and visual impairments affect approximately 6.8 million individuals in the U.S. alone.[1] Teaching science to these individuals often requires a complete redesign, especially for hands-on laboratory activities. This difficulty leads to many schools and community centers avoiding hands-on science, leaving blind and low vision (BLV) children and adults with less exposure to scientific concepts than their peers.

Efforts to adapt standard curriculum topics have produced a number of publications and guidelines,[2−9] with a specific focus on technology[10−12] as well as formal education of young students in the classroom[3,5,6,13,14] or during summer camps.[15,16] Despite these advances, the availability of activities adapted to BLV individuals is extremely limited, particularly regarding education of the general public in an informal setting.[2] Increasing exposure to science both in and out of school is likely to help BLV individuals seek careers in science, technology, engineering, and mathematics (STEM) fields, increasing diversity and participation.

Here we describe four new modules communicating simple scientific concepts in an informal environment. The modules, discussing data analysis, electrical conductivity, optical lenses, and endothermic/exothermic reactions, were presented during a 3 h science event reaching 38 BLV individuals. Prior to that event, multiple preliminary tests were performed with blindfolded volunteers.

Key concepts and outcomes for each of the modules are described below, after a brief discussion of the event and general survey answers obtained. A full description of the activities and a list of participant answers are available in the Supporting Information.

OVERVIEW AND PRELIMINARY QUESTIONS

A "Science Day" was held in 2017 at the Lighthouse of Houston, a community organization serving BLV individuals. The event occurred over a period of 3 hours. Participants of various educational backgrounds and vision levels signed a consent form and were interviewed prior to performing modules. As one of the six modules became available (two previously reported modules[2] and four new ones), coordinators directed participants to designated tables; participants were free to do as many modules as their scheduling allowed and were briefly interviewed before their departure if their schedule allowed.

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A total of 38 participants signed the consent form, and participants performed 2.5 modules on average, for an average of 16 participants per new module (see the Supporting Information for full participation data). The modules lasted 10−15 min each and were performed individually or in pairs.

Preliminary interviews revealed that the majority of participants were interested in science (30 out of 38; see Table S5.2) and thought it was important to understand the science behind everyday things, like how water boils or electricity works (37/38). Over a quarter (11/38) had attended similar events at the Lighthouse, most likely our group's earlier visit,[2] and all 11 found the previous event helpful and educational.

■ MODULES AND RESULTS

For each module, participants were asked questions assessing their prior knowledge. Then, during and/or after the modules, questions designed to assess the level of gained knowledge as well as the effectiveness of the modules were asked together with simpler yes/no questions. A complete list of the questions and answers can be found in the Supporting Information. The approximate time at each module was 10−15 min; however, participants were not under any time constraint, and the time spent at each module varied on the basis of the participant's needs.

The Sound and Feel of Data Module

Scientific data and trends, when presented as a series of numbers, can be difficult to interpret. Data are most often displayed graphically, where various characteristics—shape of the graph, appearance of peaks, slopes, etc.—reveal important phenomena. For BLV individuals, these powerful visual representations can be difficult to access and interpret.

This module converts visual signals into tactile and audible ones: we represent axes and data points with pipe cleaners and coins, respectively (Figure 1), allowing for a discussion of data presentation and trends without reliance on visual representations.

Prior to the module, only five out of 13 participants claimed knowledge of data sets; only three could give an example (see Table 1; please note that in Table 1 and subsequent tables, "No/Incorrect Answer" also includes instances when the participant did not provide an answer). In the module, the participants are guided through several pipe cleaner and coin graphs (see Figure 1). The first is a horizontal line, representing the cost of milk through the year. Next, they are shown a diagonal line, illustrating the improving grades of a diligent student over time. Finally, a graph arranged as a hill (parabola) is presented, indicating the height of a thrown ball over time. After this initial discussion, headphones and a mobile phone sound app are used to revisit the same three graphs, where the demonstrator plays higher notes when the participant feels higher y values. Participants are then asked to describe trends (standard tasks) and extrapolate the curves (extension tasks). A participant is only probed to do the extension tasks if he/she shows proficiency in the standard tasks (two out of 13 participants completed the extension tasks). The majority (10 out of 13) indicated that they enjoyed the module; two participants did not answer whether they enjoyed the module, and one indicated he did not; that participant also answered no to all of the questions before, during, and after the module. Most of the participants (11 out of 13) could name a data set example after the module, and a further seven could provide a scientific example not discussed during the module.

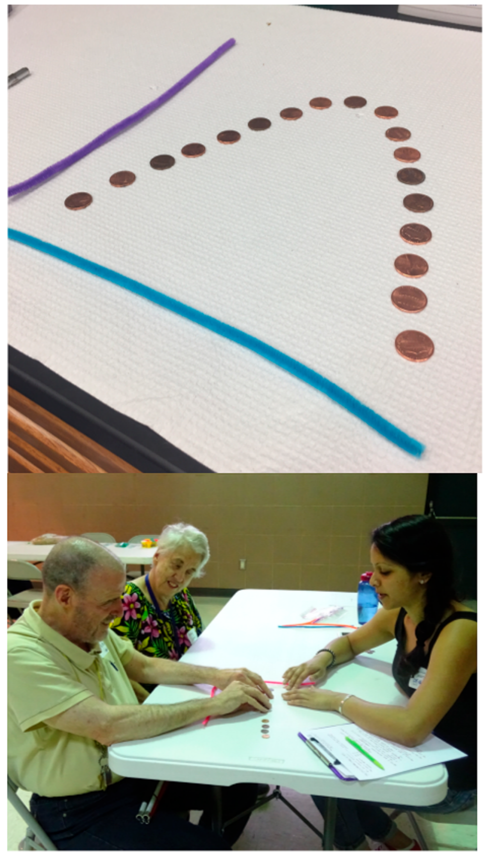

Figure 1. The Sound and Feel of Data module. (top) Pipe cleaners and coins are used to represent axes and data in a graph. (bottom) Two participants and a demonstrator performing the module.

Table 1. Pre- and Postmodule Questions and Compiled Answers for The Sound and Feel of Data Module

Questions Posed to Participants	Responses, N = 13: Yes/Correct Answer	Responses, N = 13: No/Incorrect Answer
Premodule		
1.1. Do you know what a data set is?	5	8
1.2. Can you give an example (of a data set)?	3	10
Postmodule		
1.3. Do you understand better what a data set is now that we've gone through the exercise?	11	2
1.4. Can you think of another data set from your personal life?	11	2
1.5. Can you think of another scientific example of a data set?	7	6
1.6. Did you enjoy the activity?	10	3

Conductivity of Materials Module

Electrical circuits and semiconductor devices are integral parts of society, being used on a daily basis by all individuals, with or without visual impairments. Such technologies are enabled by material-specific electrical conductivity and electronic behavior, which are important concepts that can easily be discussed at a level sufficient for most to gain a basic understanding of these fundamental properties.

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This module uses free, partially immobilized, and fully immobilized marbles (see Figure 2) in a wooden box to tactilely introduce electron flow (an invisible physical phenomenon) in metallic, semiconductor, and insulator materials, respectively. Then a simple circuit transducing electrical conductivity to sound volume is used to test the electrical conductivities of everyday objects (see Figure 2).

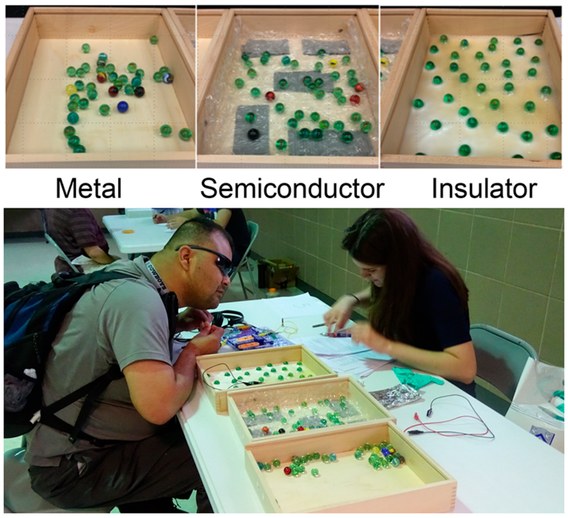

Figure 2. Conductivity of Materials module. (top) Marbles are used to represent electrons; they are either free (metal), slowed by bubble wrap (semiconductor), or immobilized by a thick layer of glue (insulator) in a wooden box. (bottom) A demonstrator (right) and participant (left) during the module.

Prior to the module, 11 out of 13 participants claimed to have heard of electrons, but only three correctly described them. Following these questions, the concept of electrical conductivity was discussed with the participants; their hands were then directed toward the boxes of marbles, and they were instructed to feel the contents of each box. The analogy with electrons and conductivity lies in the marbles' ability to move. Metals are represented by free marbles, semiconductors by marbles rolling on bubble wrap, and insulators by marbles immobilized by a thick layer of dried glue. Then, keeping the boxes accessible if needed, the participants were handed headsets attached to a circuit designed to turn current to sound. The circuit was first closed to establish a baseline of no resistance, and then a screw, a piece of semiconductor (Si), and glass were introduced in the circuit with alligator clips. The sound volume was correlated with electrical conductivity and discussed. Using the sound volume, more than half (>7 out of 13) of participants identified the conductivity characteristics of each object (a nail, a glass vial, and a piece of Si). Postmodule discussion revealed that more participants could describe electrons after completing the module, and the majority (>10 out of 13) could identify the relative ease of motion of electrons in each type of material (Table 2).

Optical Lenses Module

Forming and recording images is quintessential in scientific research as well as in everyday life and is a topic generally of interest to BLV individuals because of the connection with the human eye. While the word "lens" is a common term, the details and aberrations of lenses are rarely taught in either formal or informal settings, and they are often difficult to convey without the typical visual ray diagrams.

In this module, a simple tactile pattern introduces convergent and divergent lenses as well as astigmatism—an aberration in lenses (see Figure 3). A ray "diagram", starting with parallel beams that travel toward a lens, is formed of thick wooly rope secured to a corkboard, and the lenses are shaped plastic objects, also secured to the board, providing an easy-to-follow tactile representation of a visual signal (see Figure 3).

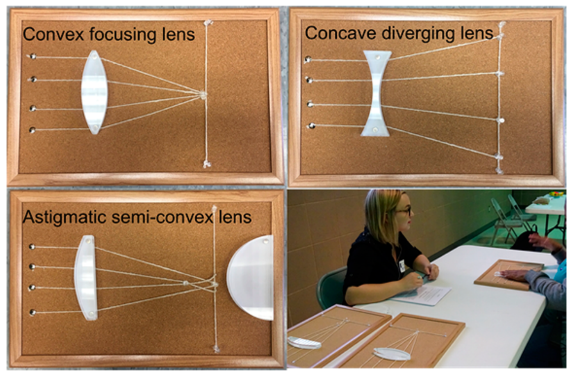

Figure 3. Optical Lenses module. Three corkboards representing (top left) convex, (top right) concave, and (bottom left) semiconvex lenses are shown; the semicircular lens is shown alongside the semiconvex setup but is not affixed to the board. (bottom right) A demonstrator (left) together with a BLV participant (right) during the module.

The participants were first asked whether they knew eyes contained lenses; most did (16 out of 20). Over half of the participants (11 out of 20) could describe a fact about lenses, for instance that they focus light. Participants were first

Table 2. Selected Pre- and Postmodule Questions and Compiled Answers for the Conductivity of Materials Module, Answers in Brackets

Questions Posed to Participants	Responses, N = 13: Yes/Correct Answer	Responses, N = 13: No/Incorrect Answer
Premodule		
2.1. Have you heard of electrons before?	11	2
2.2. If yes, could you please describe what an electron is?	3	10
Postmodule		
2.17. So to sum up, what are electrons?	8 [part of electricity or negative particle]	5
2.19. Can you define a metal in terms of electron movement (how easily the electrons move)?	11 [easily]	2
2.20. How about a semiconductor, do electrons move easily?	11 [not easily]	2
2.21. How about insulators? Do electrons move easily or not easily?	10 [no movement/not easily]	3

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presented a "typical" focusing lens (i.e., the board in the top left panel of Figure 3). Explanation was provided about the rays starting parallel and converging to a point. A divergent (concave) lens was then discussed and explored tactilely. A semicircular lens, not attached to a board, followed as a representation of a perfect eye lens and was contrasted to a semiconvex lens suffering astigmatism, an aberration that does not focus all of the rays at the same point. Participants were then asked to rate their understanding of the module on a scale of 1 to 10, where 10 was "easy to understand"; the average score was 8.6, and the mode was 10. This high ranking is supported by the positive answers the participants provided when asked whether they learned something new (see Table 3).

Table 3. Selected Pre- and Postmodule Questions and Compiled Answers for the Optical Lenses Module

Premodule Question	Responses, $N = 20$: Yes/Relevant Answer	No/Do not Know	
3.1. Did you know that your eyes contain lenses?	16	4	
3.2. What else do you already know about lenses in general and the flaws that they can have?	11	9	
Postmodule Question	**Responses, $N = 20$: Yes**	**Somewhat**	**No**
3.3. Did you learn something about lenses and astigmatism that you did not know before?	16	4	0

Chemistry and Physics of Heat Module

Hot and cold are common concepts encountered in everyday life, from coffee to ice cream and from outdoor to indoor temperatures. The concept of heat is also ubiquitous in chemistry and physics, including latent heat, heat of reaction, heat of dissolution, etc. Experiencing changes in temperature due to physical changes or chemical reactions should not require visual aids, so these concepts are ideally suited to be adapted for BLV individuals.

This module uses the dissolution of ammonium nitrate and sodium sulfate in sealed plastic tubes (see Figure 4) to describe

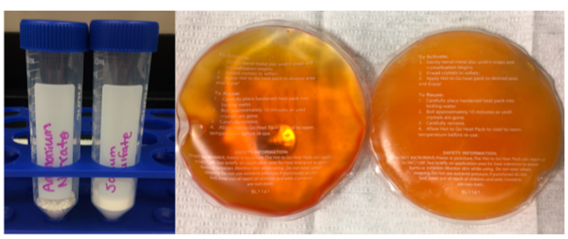

Figure 4. Chemistry and Physics of Heat module. (left) Ammonium nitrate and sodium sulfate in individual tubes prior to the addition of water. (right) Commercially available packets of supersaturated sodium acetate used to demonstrate an exothermic crystallization process.

endothermic and exothermic processes, respectively, as well as the spectacular heat released upon crystallization of sodium acetate to further exemplify exothermic processes.

The majority of participants (15 out of 18; see Table 4) had not heard of exothermic and endothermic reactions. The words were carefully explained, and the reference to the first syllable of "enter" and "exit" was particularly effective in helping participants remember their meanings. A demonstrator then

Table 4. Selected Pre- and Postmodule Questions and Compiled Answers for the Chemistry and Physics of Heat Module, Answer in Brackets

Questions Posed to Participants	Responses, $N = 18$: Yes/Correct Answer	No/Incorrect Answer
Premodule		
4.3. Have you ever heard of endothermic or exothermic reactions?	3	15
Postmodule		
4.4. What type of reaction occurred during the hot-pack module? Endothermic or Exothermic?	13 [exo]	5
4.5. Did you find this module interesting?	18	0
4.6. Did you learn something from this module?	18	0

added water to and securely sealed two vials containing preweighed amounts of ammonium nitrate and sodium sulfate. As the participants shook the tubes, the former became cold and the latter hot as a result of their heats of dissolution. The concepts were discussed with the participants, and then they were handed a packet containing a supersaturated sodium acetate solution (commonly called a "hot pack"). Crystallization induced by small crystal seeds lodged in a crystallization-initiating metal device (pressed by the participants) releases a significant amount of heat. The participants were then tested on their understanding of the concept of endo- and exothermic reactions, and 13 out of 18 correctly identified this as an exothermic reaction.

■ EXIT SURVEY AND CONCLUSIONS

After completing modules, the participants were briefly surveyed about their experience. The responses were very positive, as 27 of the 29 participants surveyed answered yes to both "Do you have a greater interest in science now?" and "Did you learn anything by participating?" and all but one stated that they would come again for a similar event (the negative respondent mentioned moving to a different city in the near future). Finally, 27 out of 29 participants agreed that it is important to understand the science behind everyday life.

For readers interested in applying these modules, we believe that there are a few steps, in addition to those described above, that may improve the pedagogical efficacy of the modules. Since our time with participants was limited, we were unable to perform a critical assessment of learning and rather had to rely on anecdotal evidence that learning occurred through the pre- and postmodule questions. Each module described here is an example of hands-on experiential learning,[17] which has been described as having four key elements: (1) an active experience, (2) reflection on the experience, (3) analysis of the concept(s) available during the experience, and (4) application of the concept(s) or skills learned during the experience to solve new problems. The hands-on modules and pre- and postmodule assessments described here are well-suited for elements (1) and (2), but, as described, did not allow for (3) and (4) to occur, ultimately limiting critical assessment of learning. Educators seeking to use these modules may wish to consider adapting additional sections to each module in order to allow participants to apply their "new knowledge" by demonstrating their ability to solve a problem similar to the concept presented during the module, depending on the participants' abilities and time available. Additional time could allow for longer periods of (2) reflection and (3) conceptualization of each module

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experience, reinforcing the capability of each module to teach participants the fundamental concepts that are communicated during the hands-on activities.

In conclusion, we have described four new hands-on modules that aim to teach concepts related to lenses, heat, conductivity, and data without relying on visual aids. These modules contribute to a growing body of nonvisual learning approaches for the informal scientific education of all individuals, including BLV individuals.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.7b00488.

Full module description and full list of questions and participant answers (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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