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Seeing Chemistry through the Eyes of the Blind: A Case Study Examining Multiple Gas Law Representations

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S *Supporting Information*

ABSTRACT: Adequately accommodating students who are blind or low-vision (BLV) in the sciences has been a focus of recent inquiry, but much of the research to date has addressed broad accommodations rather than devising and testing specific teaching strategies that respond to the unique challenges of BLV students learning chemistry. This case study seeks to identify instructional techniques that support or impede the representation of information for BLV students in the context of a typical gas laws unit in a college chemistry course for science majors. Desimone's framework on selection and attention informed the analysis. A blind student participated in five interviews to provide insights on how symbols, equations, and concepts were communicated and interpreted. Findings identified in the analysis of transcripts pertain to three communication modalities of interest: verbal, written, and tactile representations of information to aid learning. Using the results generated for practitioners, the authors generated guidelines for faculty, teaching assistants, and university administrators to improve the teaching and learning chemistry for BLV students.

KEYWORDS: *First-Year Undergraduate/General, Chemical Education Research, Hands-On Learning/Manipulatives, Gases*

FEATURE: Chemical Education Research

INTRODUCTION

Students with blindness or low vision (BLV) face significant challenges pursuing careers in science, technology, engineering, and mathematics (STEM) fields.[1] Efforts have been made to identify the barriers to student success. In particular, Burgstahler grouped such barriers into three categories:[2] (i) inadequate preparation of instructors; (ii) limited access to facilities and equipment for both students and instructors; and (iii) acceptance by educators (believing that the student can succeed in chemistry) contribute largely to this observation. As such, chemistry in a college setting poses all three of these barriers to some degree.

Fortunately, efforts have recently been made to address barriers and make chemistry more accessible. Much of the chemistry-specific work has focused on laboratory settings. Cary Supalo investigated the JAWS/Logger Pro software interface in the Independent Laboratory Access for the Blind,[3] while more work has been done to modify existing general chemistry laboratory settings.[4,5] Few sources, however, give advice to a professor or teaching assistant (TA) for accommodating BLV students in chemistry learning in a traditional lecture setting.

The Americans with Disabilities Act[6] (ADA) mandates that reasonable accommodations must be made, but does not delineate who ought to make them or how they should be executed. The American Chemical Society Committee on Chemists with Disabilities (ACS−CCD) published an easy-to-implement guide of accommodations and considerations for both secondary and postsecondary settings. The guide does not discuss the details of learning chemistry concepts, but rather provides broad and practical considerations. For example, the ACS−CCD suggests selecting textbooks and materials in time to permit alteration for accessibility, to prepare handouts electronically, and to include test dates in the course syllabus.[1] Although some of the ACS−CCD guidelines are chemistry-specific, they are not detailed enough to guide the day-to-day teaching and learning of chemistry. Another guide that specifically targets undergraduates enrolled in chemistry comes from Supalo who provides note-taking techniques, procedures for creating tactile images, recommendations for safe laboratory procedures, and strategies for expressing mathematical and chemical equations.[7] While Supalo's[7] dialogue is directed toward instructors, it does not provide content-specific pedagogical guidance for instructors serving BLV students.

Finally, in a recent paper, Boyd-Kimball introduces instructional aids to be used with a variety of chemistry topics.[8] These aids are well described, but the authors do not include the perspective of a BLV student learning with the aids. Other research has addressed the student perspective, specifically how BLV students learn chemistry using text and figures,[9] as well as how they learn different topics such as phase changes[10] and chemical reactions[11] in real-time class interactions. These authors bridge the gap between overarching ideas about learning as a BLV student to a more in-the-field, observational approach and thus narrow the focus to give instructors clear expectations for teaching particular chemistry content.

In this study, we focus on the gas laws of chemistry, with the aim of identifying specific challenges and potential solutions. Instructors desire techniques that are specific to their content and ready to implement in the classroom. In describing the "black box" of education, Black and Wiliam[12] argue that teachers will not adopt ideas if they are only presented as general principles that "leave the task of translating them into

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everyday practice entirely up to the teachers". With this sentiment in mind, this study seeks to disseminate content-specific findings collected from observations in the chemistry classroom to be immediately implemented in other chemistry classrooms.

This exploratory study identified those representations that helped the BLV student understand gas laws in an undergraduate general chemistry course. The main research question guiding the study was: What written, verbal, and tactile representations (hereafter referred to as the three modalities) of the gas laws enabled the student to construct understanding of the gas laws?

■ THEORETICAL FRAMEWORK

Visual literacy was first coined to refer to vision-competencies developed by sight as well as other sensory experiences,[13] that is, the ways in which BLV students interpret objects, symbols, and other inputs in the process of learning chemistry. It is through these other senses that BLV students develop spatial ability, a concept highly studied and correlated to success in general chemistry.[14,15] The relationship between visual literacy and spatial ability is illustrated using the example of a two-dimensional wedge and dashed representation of methane. A student with visual literacy, but lacking spatial ability, will be able to interpret the wedges and dashes as protruding into a dimension other than the plane of the paper, but cannot conjure and manipulate a mental image of the three-dimensional molecule. In contrast, a student with limited visual literacy but enhanced spatial ability can easily envision and rotate the three-dimensional structure in his or her head, but would struggle to translate the wedges and dashes into this mental structure.

BLV students experience a variety of inputs of information when engaged in a classroom environment. The challenge of deciding what to pay attention to can be described in terms of competition as delineated in selective visual attention theory.[16] Although it would be preferable to find an analogous theory that neurologically and behaviorally examines selectivity in BLV participants (does not focus on sight), the behavioral considerations of competition still apply to nonvisual modalities. Desimone postulates that divided attention leads to poorer performance, largely attributable to limitations occurring at the stimulus input stage rather than short-term memory storage (e.g., performance when two objects are shown simultaneously is poorer than when shown in succession).[16] We assert that competition and selectivity apply not only to multiple visual stimuli, but also to tactile or auditory modalities.

■ METHODS

The participant, Fantine (pseudonym) was a female, first-year, zoology major enrolled in a university general chemistry course. Data collection occurred during two weeks that included three 50-min lectures and one 50-min recitation section. The recitation was designed to provide an opportunity for students to clarify their understandings and supplement topics introduced in lecture. The first author served as one of the graduate TAs for the course and had no previous experience tutoring a BLV student. Prior to any interviews or instruction about ideal gas laws, a preassessment (Supporting Information) was developed by the first author and completed by Fantine. This preassessment was valuable to characterize her prior knowledge and inform instructional choices.

Data were collected by the first author via interviews. Two types of interviews were conducted—four informal and one formal. The purpose of the informal interviews was to capture the question-and-answer pattern in a typical tutoring session with Fantine in which the interactions were driven by her challenges with the content represented in the lecture. Questions and answers evolved; no preset questions were developed. The purpose of the formal interview (which took place following the conclusion of all gas law instruction) was to summarize her experiences, both during those tutoring sessions and in lecture, and elicit the strategies she considered to be most and least effective for her learning. The formal interview protocol can be found in the Supporting Information.

All transcripts (four informal, one formal) were transcribed verbatim and managed in NVivo 9. Analysis involved reading the transcripts multiple times and categorizing data based on context. As an example of this categorization, discussion of a piece of technology or strategy was labeled as a category. Once categories were established, short narratives describing the context of quotations in that category as well as their potential inferences were created by the first author by reviewing the transcripts and reflecting on the tutoring experiences. Then, within each narrative, one or more codes were produced to represent specific features of these narratives. Fantine's quotations were then coded throughout the transcripts. The coded quotations were then examined in the original categories for analysis (process of axial coding[17]). Approximately 10% of data were coded by the third author and yielded 92% agreement with the first author. Identifying similarities across multiple quotations, member checking,[18] and comparing and contrasting results to relevant literature served to validate the inferences drawn from the qualitative analysis. The codes generated are available in the Supporting Information.

■ ADAPTIVE TECHNOLOGIES

Various adaptive technologies designed for BLV students were used to represent and communicate the chemistry content. A Braillenote is a computer device with a refreshable Braille display and the ability to connect to the Internet. It can open and read word-processed documents, function as a calculator, and allows electronic typing in Braille. A Brailler is a nonelectronic typewriter that types in Braille on special paper. A BLV student often runs computer programs on a laptop via screen reader software called Job Accessibility with Speech (JAWS). Special scripts need to be produced for JAWS to be able to navigate the various fields in documents and on Web pages.

To create hardcopy Braille documents, an embosser prints text files onto Braille paper after the file has been electronically translated from text to Braille-by-Braille translation software. For quicker printing, a Dymo Braille label maker makes quick Braille labels to adhere to objects. Several instruments create raised images of various levels of quality. A tactile graphic maker (commonly referred to as the "toaster") transforms printed images on thermal paper by using heat to raise the printed portions. Similarly, a "thermopen" creates raised images on a similar type of paper. Finally, a screen wire mesh placed inside a frame produces a tactile image on regular paper when crayon is pressed down upon a hard surface.

RESULTS AND DISCUSSION

From the results of the preassessment, it was clear that Fantine had very little prior knowledge of gas laws. She did recognize the gas laws by name, but was unable to answer any of the preassessment questions correctly. Each of the themes that emerged from the data are described below, as well as potential suggestions for teachers grounded in the data provided by Fantine's own descriptions of what contributed to (or hindered) her learning.

Tactile Representations

Although potentially helpful, tactile representations can include representations unfamiliar to BLV students. For example, Figure 1 (made tactile using a tactile graphics embosser) was used in an informal interview to teach Fantine about the direct relationship between pressure and temperature at constant volume. However, several features in Figure 1 were unfamiliar to Fantine: the pressure gauge (circle with inscribed triangle), the container (cylinder), and the particles in motion (black circles with three lines following). Fantine was not familiar with how a pressure gauge indicates pressure, nor was she able to comprehend the analogy of a speedometer or an analog clock (as she was also unfamiliar with these). Ultimately, the idea of a needle rotating clockwise in a circular container needed to be explained before she could comprehend that the three cylinders contained gases at different pressures.

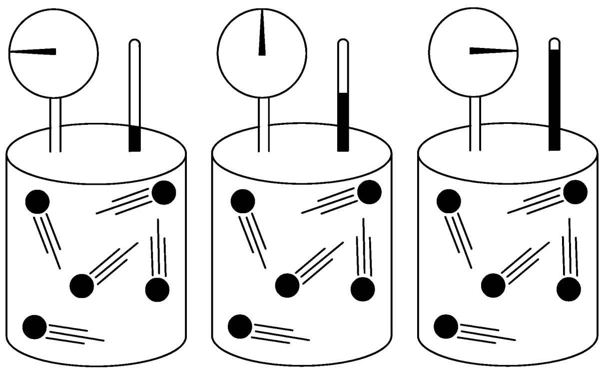

Figure 1. Gay-Lussac's law representation. This particulate level illustration of Gay-Lussac's Law requires interpretation of multiple features, such as the illusion of motion. However, such representations create unique interpretation challenges for students with BLV.

Similarly, Fantine could recognize the shape of a cylinder, but was unaccustomed to mentally transforming a two-dimensional drawing into a three-dimensional object. Lastly, Fantine was completely unfamiliar with the two-dimensional convention of parallel straight lines to represent three-dimensional motion. Interestingly, the features of this particular illustration contrast some of the standards put forth by the Braille Authority of North America and the Canadian Braille Authority.[19] In particular, Unit 2 of their guidelines warns against too much clutter and displaying two-dimensional cross section views versus three-dimensional perspective views if that level of depth is unwarranted. Fantine eventually learned all of these conventions, but only after lengthy descriptions and time to practice. Developing these visual literacy skills was necessary prior to understanding the gas law concepts that were being illustrated in the tactile pictures. It bears noting, however, that Fantine often faced the task of acquiring both concepts and conventions at the same time, leading to frustration and confusion.

With a screen reader transmitting via headphones, the professor talking to the class, and a Braillenote to translate PowerPoint text to Braille, Fantine had three or more sources of information to process during lecture. The challenge of trying to simultaneously attend to and process all this information is best understood in terms of competition in the selective visual theory. For a sighted student, the lecturer elaborates on a PowerPoint presentation (auditory input) for the student to sync with the images and text displayed on a slide (visual input), while the student outputs information into the form of working on a exercise or taking notes (tactile). Thus, a student with sight gathers information via two modalities (auditory and visual) and ought to be able to switch between multiple sources of information competing for one modality of input. In contrast, Fantine listened to the instructor (auditory input), had the PowerPoint slides translated to Braille (tactile input) or read by JAWS (second auditory input), experienced raised images (second tactile input) while the TA explained them to her (second or third auditory input), and then took any notes or works exercises by typing on the Braillenote (tactile output). Figure 2 shows a schematic of the many inputs of information that compete for attention.

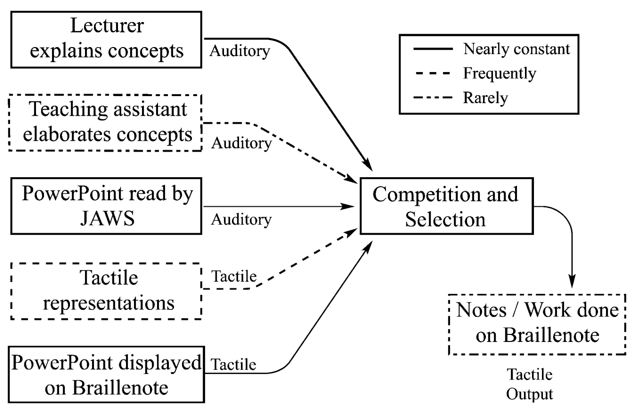

Figure 2. Schematic of inputs of information showing the multiple sources of input information that compete for attention.

It was common for four or five of these information inputs to be occurring simultaneously. In the lecture setting, Fantine was frequently unable to interpret tactile images, other than the most commonplace illustrations (simple shapes or labeled graphs), without explanation from the TA. She often chose to concentrate on the TA explanation of an illustration while exploring the image with her hands, but she could not possibly listen to the instructor or follow along on the PowerPoint slides at the same time, enhancing the negative effects of divided attention:

> *Sometimes I'll just shut JAWS up because that's one less thing I have to pay attention to.... I got really kind of overwhelmed in the middle of the lecture, I was like, whoa, I mean there was like so much information flying around.*

These comments, made during the more math-intensive portions of ideal gas laws, suggest that competition was an ongoing problem. In the end, Fantine suggested that although she recognized that divided attention led to poorer performance, she could not decide which input should or could most

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readily be ignored and which was the most valuable to her learning.

Chemistry One Line at a Time—The Brailler versus the Braillenote

The greatest setback for learning with the Braillenote was the need to constantly scroll throughout a document or homework problem in search of information one line at a time. Because the Braillenote display is less than one foot in length and Braille itself takes up a lot of space, only a limited amount of text can be displayed in one line. This limited display of information repeatedly caused challenges for Fantine when completing problems and reading through notes:

> *[I have to] scroll with one thumb on the Braillenote, um, it's annoying, it takes forever 'cause you usually miss what you're looking for.... Scrolling up and down between these lines is a pain.*

Figure 3 exemplifies this difficulty as it pertains to simply reading a straightforward gas law exercise. A number followed by a colon indicates line numbers typed on the Braillenote. In this example exercise, there were three pieces of information (or six, counting the associated units). Every time Fantine transferred from the exercise to the workspace, she had to scroll up one line at a time, find the information in the exercise, and then scroll down one line at a time to get back to where she was.

INTERVIEWER: A balloon is filled with hydrogen to a pressure of 1.35 atm and has a volume of 2.54 L. If temperature remains constant, what will the volume be when the pressure is increased to 2.50 atm?

FANTINE: *[This is] Boyle's Law because it deals with pressure and volume.*

—Written on Braillenote—
1: A balloon is filled with hydrogen
2: to a pressure of 1.35 atm and has a
3: volume of 2.54 L. If
4: temperature remains constant, what will the
5: volume be when the pressure is increased
6: to 2.50 atm?
7:
8: P1V1 = P2V2
9: V2 = (P1V1) divided by P2
10: P1=1.35 atm
11: P2=2.50 atm
12: V1=2.54 L
13: V2=?
14: V2 = (1.35 atm * 2.54 L) / 2.50 atm
15: V2=1.37 L
16:
17: Unit conversion
18: 2.3atm is how many torr?
19: B1: 2.3 atm
20: B2: empty
21: B3: 760 torr
22: B4: 1 atm
23: =1700 torr

Figure 3. Braillenote representation of Boyle's law exercise. This illustration shows what was typed by Fantine to complete a Boyle's law exercise.

Clearly, scrolling was cumbersome when searching for information. A less obvious, but more significant barrier to working exercises was the task of transferring information from a reference (exercise, table, equations, rules, etc.) to a workspace (work to a solution, notes, exam response, etc.). Although Fantine did not seem to have a deficiency in short-term memory capacity, she (as would be the case with most general chemistry students) was unable to solve this exercise without writing down pieces of information. This need to write down information revealed new considerations when using the Braillenote:

> *Jumping back and forth from a work file to a file with the problem in it is a pain because you lose what you had and that's part of the problem with some of the exams I think, I get mixed up.*

When Fantine was unable to retain information from the first read-through of the exercise, she had to return to the exercise in a different file, scroll to find the necessary information, return once more to the work file and continue where she previously left off. In Figure 3, the three pieces of information needed to solve the exercise are located on three different lines, making it much more difficult to find the particular information she was looking for when writing out her work for the exercise. Even worse, sometimes a number was on a separate line than its corresponding unit. This separation of a unit from the measured value presented yet another opportunity for errors and misunderstanding. Fantine needed to revisit several parts of the original exercise multiple times while solving it because of this transferring back and forth. At one point, Fantine remarked that other members of BLV community thought it implausible to work out mathematical exercises on a Braillenote:

> *And I told someone I was working through this stuff with a Braillenote and they said, "Are you crazy?"*

Additional disadvantages of Braillenote included difficulty translating Microsoft Word 2007 .docx files and .pdf documents. The Braillenote had a tendency to interpret some symbols and numbers mixed with letters typical in symbolic representations in chemistry. As an example, Figure 4 shows the misinterpretations of a seemingly trivial symbol for temperature in kelvin (K). Despite these limitations, the Braillenote did offer advantages: Internet access, search features to help find key words in documents, note-taking in lecture (rather than carrying the sizable, loud Brailler and its paper), connection to a computer to display PowerPoint presentations in Braille, and translator capabilities between Braille and text.

One way Fantine successfully mitigated the issues presented by the Braillenote was to work exercises and take notes on a Brailler. When asked which device she would prefer after working a gas stoichiometry exercise on her Braillenote, she said

> *Umm, definitely a Brailler so I can see everything at once, at least, all the information that I have on a separate sheet, like the chemical reactions, the volume, the temperature on a separate sheet.... It would be a lot faster for me to work this out on a Brailler, I mean it's not impossible for me [to work it out on a Braillenote] because I just did it.*

The clear preference here is stated for the Brailler because it saved time by placing information into an easily accessible, searchable space. Fantine often alluded to the preferential use

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INTERVIEWER: Describe briefly your reader's ability to clearly communicate the special symbols and notation of this unit to you. So what were some things that show up really clearly, and what things show up not so clearly?

FANTINE: Any sort of equation, or anything that has to do with numbers this Braillenote is not going to pick up very well. Um, if it's a standard number, like 225 Kelvin, it's going to say, if I have the speech turned on, usually I won't 'cause I'm reading on the Braille display, but if I turn the speech on it will say 225K, I have to stop it, go back, and it usually defeats the purpose of the speech, but I usually have to read that 225 Kelvin, not just 225 something it thinks is a K, which can happen quite a bit. It'll interpret things a little bit differently than what it's supposed to be. In the homework a lot of time, if I'm trying to open them on my Braillenote which I've totally given up on 'cause it doesn't work very well.

Figure 4. Fantine's interpretation of temperatures with Braillenote, and her comment on interpretation of certain symbols.

of the Brailler over the Braillenote for this very reason, and Fantine had fewer misunderstandings and questions on writing-intensive tasks on a Brailler.

PowerPoint Presentations

In Fantine's classrooms, PowerPoint presentations were commonly used to guide instruction. Electronic images, multiple inputs of information, and transitioning of slides were all challenges for Fantine. Because gas laws were taught with graphs and illustrations to model both macroscopic and particulate behavior, the images themselves contained important information to be learned. Fantine was concerned with missing key information whenever JAWS said an image was present on the PowerPoint:

> *When JAWS says "image", my brain kind of goes like, okay, how do I understand what's going here, but then descriptions and models help a lot.*

The descriptions and models presented in lecture ranged from tangible objects (model kits, interactive apparatus, tactile images, etc.) to verbal descriptions of images. It is important to note that the tangible objects were not designed by the instructor but rather by the TA as supplemental materials to be explored by Fantine in real time during the lecture. Therefore, she had to wait until after the lecture to revisit the models if she did not immediately understand them. She spoke of her preference to experience the illustrations beyond just a verbal description:

> *I guess I have to say again that everything that can be seen tactilely or that can be explained that was in, a sort of format that might have been confusing is really, really helpful.*

It should be noted that although specific grades are not presented for protection of the participant, Fantine performed very well on the exam dealing with gas laws and was successful in the general chemistry course.

■ RECOMMENDATIONS FOR TEACHING ASSISTANTS AND INSTRUCTORS

The findings from this case study, in addition to working with Fantine for over a year, have yielded new insights about the conventions used to guide the planning and delivery of chemistry instruction of ideal gas laws for BLV students. The first and most important premise focuses on professors and TAs (collectively referred to as instructors). Simply stated, this means instructors must believe in the potential for a BLV student to achieve success in chemistry and be willing to accommodate instruction and assessment.

As for more specific recommendations, instructors should encourage students to work math-intensive chemistry exercises on a Brailler, and at minimum, tests need to be Brailled as opposed to electronically administered. A Braille reference page with constants, equations, and short phrases should be made available prior to learning material for quick referencing throughout the course. This alone could dramatically reduce the amount of time spent searching for information one line at a time and thereby reduce frustration.

Additional time is not typically provided when working problems in a classroom setting, but most university disability policies include giving students additional time on tests. It proved advantageous to not only have additional time, but to permit Fantine to have small breaks during longer tests. Even when, by the first author's judgment, Fantine had a firm understanding of the concepts and problem solving tasks, certain solutions took a long time to compute and led to a high level of mental fatigue. In addition to time considerations, BLV students experience other challenges in the lecture setting. When instructors habitually say "this" and "that" while pointing to text and illustrations on slides, it needlessly complicates the task for a BLV student to follow the lecture. In addition, to ease transitions with PowerPoint slides, instructors should include a tone at the end of each slide (not each animation) to indicate when the next slide is displayed for the class.

Lectures incorporating PowerPoint present content through multiple modalities of input (auditory and tactile) and cause competition for attention. As such, not all images need to be re-created as tactiles, but all images ought to be described to some degree. The criteria for this decision seem largely based on the potential benefit of experiencing the illustration fully versus only hearing a description of it. For example, if when talking about nitrogen, a gas tank is shown to introduce it, it is probably no more beneficial to create a raised image than it is to caption the image as "Illustration shows a gas tank containing nitrogen." In this example, no concepts are introduced, so no tactile representation would be necessary. This shortens the amount of time required to interpret information in a figure and focuses the student on a more productive stimulus within the figure. In contrast, images containing something the student has not encountered previously, such as a particulate-level model of a gas under specific conditions, might prove to be difficult to describe verbally and is an example of an illustration that ought to be represented tactilely.

■ RECOMMENDATIONS FOR COLLEGE ADMINISTRATORS

Section 504 of the ADA[6] states that all school systems and universities must provide reasonable accommodations for students with disabilities; however, offering flexibility may not include assigning specific roles and responsibilities (financial or otherwise) to the various entities across the institution. In this case study, the responsibilities to craft accommodations and to finance the costs of these accommodations oscillated between the chemistry department and office of disabilities. This back-and-forth system jeopardized the single most beneficial accommodation in Fantine's learning; one-on-one tutoring with either a TA or professor:

> *I think what really stands out is being able to um, meet with you [TA] after lecture and be able to figure this stuff out.*

It was not uncommon for the first author to work one-on-one with Fantine outside of class for six or more hours every week. Instructors typically do not have this kind of time to devote to one student, whereas, with the proper resources, a TA's responsibilities could be modified to include this time allotment. The findings of this study and the first author's experience show that neglecting to provide one-on-one tutoring is not a viable option. Reasonable accommodation per the ADA would mean someone ought to be assigned the primary responsibility and resources (time, money) to generate ways to make lectures and laboratories accessible. This task will require knowledge typically distributed across multiple persons to be coordinated. For example, knowledge regarding available equipment, technologies, and expertise in educating a BLV student is unlikely for a chemistry TA, but typically accessible through an office of disabilities. On the other hand, strong chemistry content knowledge (and furthermore, pedagogical content knowledge[20]) is usually nonexistent in an office of disabilities.

To ensure efficiency and effectiveness with regard to delivery of accommodations, the authors believe that the responsibility of accommodating the learning of chemistry by a student with BLV should be placed on a chemistry TA. Consolidating these responsibilities in one person will enable the TA to build a repertoire of techniques through consistent and frequent meetings with the student, leading to a better understanding of the accommodations necessary for that particular individual. In contrast, if time were to be split across the office of disabilities, the professor, and the TA, subtle yet valuable insights could be lost to each party involved in the imperfect process of communication. Sharing the nuanced information related to the student's learning strategies among these three entities would be difficult and increases the instructor time commitment. Moreover, it is likely that each entity would adopt divergent strategies depending on their own individual strengths, leaving the student to adapt to multiple teaching styles and to perhaps coordinate and transport equipment from one instructional setting to another. This lack of consistency would add even more variability to an already chaotic learning environment.

Two challenges that must be addressed are likely to arise with a teaching assistant taking on most of these responsibilities. First, TAs are generally tasked to help entire classes learn chemistry, and usually more expensive than (an) undergraduate student worker(s). These issues are dependent on one another, as allocating a TA to work solely with a student with BLV will likely spur the need for an additional TA to support more traditional assignments of laboratory instruction, recitation instruction, or exam proctoring. Providing appropriate accommodations in a general chemistry lecture and laboratory could easily exceed a minimum of 20 h per week to adequately assist one BLV chemistry student. Therefore, it is not always plausible for a graduate student to take on additional duties outside of working with the BLV student.

Second, offices of disabilities ought to assist chemistry departments to fund such a graduate student. Most departments do annual budgeting. Even a few months advance notice that a BLV student will enroll in a chemistry course could be too late for a chemistry department to recruit, admit, and allocate funds for an additional TA. Administrative policies to provide specific, day-to-day accommodations may have good intentions when they require advance planning, but these regulations may well create a practical implausibility that leads to minimal fulfillment, as opposed to genuine accommodations.

Lastly, admissions offices ought to proactively work with chemistry departments when admitting BLV students. When students identify chemistry or related science majors that will require chemistry coursework, preparations ought to commence well in advance of the BLV student arriving on campus. This preparation time is crucial for funds to be reallocated or requested in order to provide accommodations. Also, as strategies for accommodating students accumulate, chemistry departments will be able to provide a much more detailed picture of what a student should expect when taking classes. This could be crucial information to guide BLV students to choose a university truly committed to their success. As such, these strategies ought to be shared with other departments in the university, as well as other universities.

It was not the purpose of this research project to validate these suggestions, but certainly the experiences with Fantine surfaced them. The implications for the learning of chemistry by BLV students must focus on informing teaching and administrative practices, logistical considerations when working with these students, and consideration of the advantages and limitations of various technologies often accessible to these BLV students.

ASSOCIATED CONTENT

Supporting Information

The preassessment; formal interview questions; coding list. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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