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Accessible Teaching and Learning in the Undergraduate Chemistry Course and Laboratory for Blind and Low-Vision Students

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ABSTRACT

Symbolic, spatial, and visual information, which is important for comprehending and learning physical and natural sciences, is not readily accessible to blind and low-vision (BLV) students in the undergraduate chemistry classroom, laboratory, and virtual environment via conventional means (through print and images); thus, creating a disadvantageous and inequitable situation. Appropriate instruction methods can be used to include these differently abled students in the learning process while also enhancing the learning outcomes of a diverse student population. By considering teaching approach, universal design practices and utilizing adapted methods, collaborative learning, non-visual assistive technologies and equipment, chemistry classroom/laboratory work for BLV students can be transformed from a passive experience to an active one. By creating the least restrictive learning environment, BLV students are enabled to become independent workers. Non-visual ways (i.e., auditory, and text-to-speech applications, speech-enabled equipment, tactile graphics, and physical artifacts) by which BLV students can conduct their work are described and practical ways for faculty to enhance teaching are presented.

KEYWORDS

First-Year Undergraduate/General, Second-Year Undergraduate, Upper-Division Undergraduate, Curriculum, Laboratory Instruction, Computer-Based Learning, Hands-On Learning/Manipulatives, Laboratory Equipment/Apparatus, Learning Theories, Student-Centered Learning, Inclusive Teaching

MEETING THE LEARNING NEEDS OF THE DIFFERENTLY ABLED

In a course syllabus, an instructor gives information about available college and university resources and indicates how students can contact disability services. This notification will alert affected students about filing paperwork and getting accommodations in place. Nonetheless, how often do we as instructors see this information as a reminder that there are learners in our courses who are differently abled, that we need to alter our usual approach to teaching to be inclusive? This adjustment does not have to be drastic, burdensome, or unproductive, it can be taken by us as an opportunity to investigate effective ways to engage all students and to implement an instructional design that will assist the diversity of learners in the classroom and laboratory.

Guidance for creating accessible and effective instructional practices and learning environments can be drawn from universal design for learning (UDL) principles. The purpose of UDL is to formulate practices that account for differences and variations in ability among learners and informs the process of course development. Background information may be obtained from a book,[1] which was used as the focal point for a faculty development project aimed at increasing accessibility of college STEM courses.[2] Application of UDL principles in course implementation incorporates multiple means for representing knowledge, measures for students to demonstrate their understanding, and ways for engaging students. An analysis of a general chemistry curriculum based on UDL criteria may be used as a template for revealing areas where accessibility may be improved in other courses.[3]

In this article, practical ways to enhance the learning environment of blind and low-vision (BLV) students will be suggested; those methods are compatible with promoting learning for all. Let us presume that students who have knowledge of their needs will make arrangement for their accommodations, are proficient in the use of adaptive and assistive technologies, and that disability services will act as a resource for students and instructors. This will allow us to perform the faculty role as the teacher, one whose focus is on establishing learning objectives and outcomes in the undergraduate laboratory chemistry course.

TEACHING APPROACH AND LEARNING STYLE

At many junctures during a course, an instructor considers learning objectives and outcomes and how to assess knowledge, understanding, and thinking skills. None the less, there is an equally important need to choose teaching approaches that will successfully engage students. By carefully considering the nature of these approaches, instructors can create engaging learning opportunities for all students; they can also gain a better understanding of ways in which a learner with a disability may become fully integrated and why an adaptation or assistive technology is effective.

In his theory of learning, Howard Gardner identified and characterized seven "multiple intelligences".[4] By considering five of them, language, an understanding of others, logical-mathematical analysis, spatial representation, and the use of the body to solve problems, ways of engaging students in the learning process may be envisioned. Although terms such as linguistic, logical–mathematical, interpersonal, visual, and kinesthetic have been associated with modern learning style theories to denote learning modes of individuals, they can none the less be used to generate ideas about multi-sensory teaching options. Learning style terminology is borrowed here only to help identify techniques that engage students in the learning process. It is not implied that aligning instructional methods with learning styles will have a positive impact on learning outcomes, as evidence is not available to support this[5]. As appropriate, formulate activities that are correlated with learning objectives which will help students achieve desired outcomes. These objectives can, for example, be based on the familiar cognitive domain category of Bloom's original Taxonomy[6],which has six levels: Remembering, Understanding, Applying, Analyzing, Evaluating and Creating. As BLV students may have to utilize multiple and perhaps less-preferred routes to learning, it is necessary to provide a variety of instruction delivery alternatives.

The aims of this article are to help chemistry faculty:

- Understand adaptations and assistive technologies
- Become familiar with how non-visual learners use them
- Recognize challenges faced by BLV learners
- Choose universally effective teaching practices

The scope will be limited to chemistry instruction for those learners who have limited vision or who are blind. Nonetheless, applications to biology and physics will be apparent and there will be recognizable benefits for learners who are not challenged by a disability.

PROVIDING ACCESS TO SYMBOLIC, SPATIAL, AND VISUAL INFORMATION

Symbolic, spatial, and visual representation of information, which is important in comprehending and learning chemistry, is not accessible to BLV learners in the classroom or virtual environment in conventional ways[7] (written form, slide presentations, computer images, screen sharing, and simulations/visualizations). Moreover, as visualization technology become more widespread, BLV learners will continue to be marginalized due to inherent inaccessibility.[8] Simulations and animations are now prominent and widely used in science instruction, and yet only a handful of the large number are BLV accessible. The user interface of these is not compatible with screen reader software. To eliminate the substantial inequity that this creates, developers of these teaching tools must not release their product unless it is truly BLV-accessible, and faculty should choose only accessible options. To counter further accessibility disparities in visualization (and other) applications, developers must consider building in accessibility features from the outset, consider the needs of the end-user, and recognize that it is the data/information that is the key output and not the rendering of the visual experience. A focal point for obtaining resources by developers and higher educators is the Center of Excellence in Nonvisual Access (CENA) at the National Federation of the Blind.[9]

Nonetheless, there are simple instructor-executable techniques that can be used in the classroom to make knowledge acquisition more accessible to BLV students. They are listed below and are commonly promulgated by instructional designers:

- Use digital textbooks and open education resources that are compatible with accessibility standards
- Give notes/course materials in accessible digital form (.txt, .doc, .pdf) and slides (.ppt) prior to class, via a Learning Management System (LMS)
- Provide a list of special terms and vocabulary and/or glossary
- Write using large diameter chalk or high-contrast, broad-tip markers
- Use clear, detailed, specific verbal descriptions and read aloud when presenting information from board or slides
- Have a video or document camera with display monitor in the classroom
- Provide simplified, large-print diagrams and handouts
- Provide models and tactile drawings and representations for student use
- Post captioned lecture recordings and videos (with transcripts)
- Ensure that LMS, web-based tutorials, quizzes, homework, and applications software are accessible
- Images and figures given in digital format should be tagged with alt text descriptive annotations
- Render formulas and equations in accessible format (i.e., MathML)
- Offer tests and assessments in alternative format, including placement tests and standardized exams (contact the testing center and the originating professional organization, e.g., ACS Examinations Institute)
- Use interactive teaching methods to promote a dynamic learning environment

For students with vision limitations, alternative ways of offering content—including equations, figures, and diagrams—are needed. When reading aloud from handouts, a chalkboard or white board, or presentation media, instructors must unambiguously communicate information. It is especially important to transmit the detail and structure of formulas, equations, and mathematics. Clearly indicate subscripts, superscripts, symbols, operators, and functions and the logical meaning. Consider, for example, the importance of properly describing the quadratic formula to convey, without confusion, that the square root operates on the $b^2 - 4ac$ term (as part of the numerator) and that $2a$ is in the denominator.

While sighted students will take and review notes in handwritten form or on a laptop, BLV students will use screen reading software on a laptop and/or a tactile input/output device for this purpose. Screen reading software produces synthesized speech from text in files, keyboard entries, application controls and menus, and operating system commands. Not only is the text of interest read aloud, so are the application and operating system commands, thereby making it difficult at times to simultaneously listen to and operate the device and listen to the classroom presentation.

A refreshable Braille display is a self-contained device that offers notetaking functionality. When used to review notes, the Braille code (each character is represented by 6 raised dots in 3 × 2 array, a cell) is displayed electro-mechanically in a 32-cell line and interpreted utilizing the padded part of the fingertips. As output changes, the cells are refreshed. The challenge for the BLV student is that the continuously refreshing Braille display requires considerable mental focus, scrolling, and recall to capture and synthesize the content—a time-consuming operation—while participating in activities.

As textbooks support the acquisition of scientific knowledge and are a powerful tool in teaching concepts and principles,[10,11] it is vital to provide them in a BLV-accessible form. Audio versions of texts are produced in many formats, including EPUB. Paper-embossed Braille provides content in a large format (including graphs) and is used to reproduce textbooks for BLV students. Because there is often a delay in obtaining Braille on paper textbooks and laboratory manuals, BLV students often find themselves at a disadvantage in not having material to review according to the course schedule. It is beyond the scope of this article to discuss issues related to the inadequate nature of accessible published chemistry material and delays in timely acquisition of accessible science textbooks. Currently, tactile drawings and accessible STEM textbook figures and graphics do not realistically support learning by BLV students. As noted in one study: more physically engaging tasks enhance comprehension, and that listening to scientific materials using a synthesized voice may reduce comprehension ability compared with hard-copy Braille (.brf format) and Braille displays.[12] It is essential to have accessible textbooks for BLV students; without them, these students are excluded from the educational enterprise.

INTERACTIONS AND TACTILE INFORMATION

Whether in small or large classes, the non-visual learner (and those who prefer language, discussion, and hands-on manipulation) will be engaged by an instructor who conscientiously fosters student participation, uses verbal cues (name/directions), and provides precise detailed descriptions and explanations when talking about slides and handouts, in presenting equations, figures, and diagrams, and showing models. Instructors should encourage sighted students to do the same. When doing electronic polling, assure that clickers are accessible and that visually presented results are thoroughly described. Spoken “yes”, “no”, and letter-designated responses can replace the use of clickers, and handclapping in response to questions can be an engaging way of learning assessment.

To enhance understanding for non-visual learners, and address learning through kinesthetic ways for others, make use of three-dimensional objects, and tactile figures and diagrams. During classroom presentations, non-auditory tools such as physical artifacts that can be handled will augment presented content for all. Objects can be produced on a 3D printer from a digital file generated from a computer-aided design program, a 3D scanner or library file. This technology is becoming more available, even to the extent that the virtual image can be captured on a cell phone and then used for printing. The printers are becoming less costly and are finding their way into academic settings. Plentiful physical models are available from science instruction catalogs.

RAISED LINE DRAWINGS

A simple approach to offering accessible graphs and figures is to make raised line drawings on Mylar film using a stylus or pen and rubberized (Sewell) pad. This is a convenient way of supporting explanations and providing quick responses to questions that may arise during help sessions. To make more informative tactile graphics, images may be produced on heat-sensitive “swell form” paper. A diagram or figure (from textbook or computer output) is printed on this thermally sensitive paper from a printer or copied on it using a photocopier and is subsequently thermally processed to obtain the tactile drawing. Text on the page may be subsequently annotated with Braille if needed.

More detailed graphics with higher resolution may be produced by importing specially formatted files into a tactile graphics program (edited if needed) and outputting to an embosser. Examples of files that can be used directly with embossers may be found in the American Printing House for the Blind tactile graphics library;[13] however, the collection does not contain graphics that can support instruction in upper-level chemistry courses. The lack of availability of tactile graphics is a prevailing problem. In lieu of this, faculty can identify or create original uncluttered figures of their own that convey the essential content and provide them to disability services for processing. If a concerted effort among faculty, groups knowledgeable about BLV issues, scientific professional organizations, and textbook publishers is made, a standard collection of tactile figures to support the chemistry curriculum can be developed.

Emerging technology includes the tactile-audio tablet, where a user touches locations on a tactile overlay, haptic electronic diagram, to elicit audio feedback from software,[14] which is potentially useful in investigating chemical structures. A web portal, MOLInsight, cataloging software for verbalizing molecular structures is worth investigating[15] and 3-D structure visualization protocol is described elsewhere.[16] A refreshable display is being developed to present well-resolved graphics dynamically in real time,[17] but is not yet available to support figures needed in the chemistry curriculum.

Blind students taking science courses routinely do without tactile aids at institutions in the U.S. and worldwide[18,19] due to lack of availability and concerted development efforts. This contributes to an unequitable situation and results in the low retention of BLV students in STEM disciplines and is reflected in National Science Foundation and National Center for Education Statistics survey data.[20,21] By selectively choosing tactile figures and diagrams for BLV students, faculty will become cognizant of the graphical resources that enhance course objectives that will promote learning for all students.[22,23] Raised line drawings can be supplemented with three-dimensional manipulatives to illustrate concepts and physical and chemical processes.[24]

COMMENTS REGARDING ONLINE INSTRUCTION

There are unique accessibility issues that arise for BLV students during synchronous sessions when in the video conferencing environment. While using screen reading software, such as JAWS (Job Access With Speech), NVDA (Non-Visual Desktop Access), Narrator, VoiceOver TS, screen sharing, and video streaming content will not be read aloud. Screen reading software does not render video images of text into speech or extract text from the video feed. Therefore, an alternative way of communicating information by the instructor from such sources is needed. When presenting synchronously, using a whiteboard feature or in screen share mode, a detailed spoken summary describing content is required. Deliberate attention to verbalizing complex information, equations, and mathematic expressions will be necessary—and of value to all students. Providing a document file to students before or after the presentation will serve as a good learning aid. Also, consider typing in real time in a displayed word-processor, using large font during a screen share; this will eliminate issues with unclear handwriting for sighted students and allow for file save to share afterwards. Even though slide presentations are readable using screen access software under usual circumstances, they are not during a screen share as they are video content. Therefore, be thorough in stating information on each slide as it is presented: provide the slides to students prior to the session, taking care to give a detailed description of graphics that appear as images. During the online class, team or group interaction and collaborative work is possible using the discussion board and through breakout rooms, respectively. In the group session, file sharing of accessible documents will facilitate work for BLV students. Note that the chat function does not facilitate real-time interaction for BLV students in some conferencing applications.

For asynchronous classes, videos may be recorded and then uploaded to the learning management system after third-party processing, closed captioning, and transcription has occurred. Because audio-to-text conversion is not completely accurate, it is necessary to check and correct errors in the transcript, especially when scientific terms are used. Equations and mathematical expressions must be reproduced in meaningful form for BLV readers

WEB CONTENT AND MATHEMATICS ACCESSIBILITY.

In a web-based course, accessible information can be delivered in many digital formats (including .docx and accessible .pdf). Scanned documents and screenshots should be avoided, as they may not be accurately rendered by optical character recognition (OCR), whose use introduces another step for the BLV student. Moreover, not all Internet resources are accessible to BLV learners. Not only is the available information on a web page important, logical display and ease of navigation is critical. Therefore, Web Content Accessibility Guidelines (WCAG)[25] were created, providing a single shared standard for web content accessibility that meets the needs of individuals, organizations, and governments internationally. The WCAG documents explain how to make web content more accessible to people with disabilities. Web “content” generally refers to the information in a web page or web application, including natural information such as text, images, and sounds, code or markup that defines structure, presentation, etc. Screen reader users utilize keyboard commands to identify formatting, locate headings and structural elements, find links, buttons, combo boxes, edit fields, , and other active entities. Unless a web page is configured properly, BLV users will have difficulty in interacting with the site. Numerous web content accessibility checkers are listed[26] by the Web Accessibility Initiative. An illustrative evaluation tool is available by Webaim.org.[27] Even though web content may meet WCAG standards, BLV users can encounter difficulties in successfully interacting with a site due to poorly designed and inoperable structural and navigation features. As the LMS is a key component of course delivery, it must meet WCAG version 2.1 standards. Prior to interacting with a webpage, a screen reader user will do a preliminary exploration to investigate structure and content. One consequence of this, is that a BLV student will need to use additional time to navigate online quizzes and exams. It is not uncommon for a BLV student to use more than one browser and type of screen reader to successfully use a particular web site. This includes resources and systems that are usually accessed through the institution home page.

To handle mathematics and science notation, the Nemeth Braille Code is available to BLV users, and it is augmented with the Code for Chemical Notation[28] (currently under revision). Alternatively, mathematical expressions can also be made accessible in many contexts (documents and webpages) using Mathematical Markup Language(MathML).[29] When equations and mathematical expressions are in MathML, they can be read correctly by a screen reader. It is now possible to embed accessible mathematical equations in documents generated in various applications and systems and within different areas of learning management systems (the native equation editor may support MathML, thus production of accessible expressions). When preparing online quizzes and exams, equations and math expressions must be accessible, that is, not as embedded images. MathType,[30] is an example of a free-standing and add-on graphical equation editor that may be used to generate accessible mathematical expressions. Entry of symbols or text is done with mouse or keyboard in a full graphical

WYSIWYG environment (for sighted users). This is in contrast to document markup languages where equations are entered as “code” in a text editor and then processed into a typeset document as a separate step, such as with LaTeX, a potentially useful language for BLV students.[31] In either case, equations can be printed, exported or further processed into Braille output.

BENEFITS OF THE INTERACTIVE LEARNING ENVIRONMENT

Creating an interactive environment in the classroom or virtual space will promote learning for all students; that is, by using activities that engage students. This is accomplished by using active teaching and facilitated learning. Although a variety of pedagogical methods are in use (too numerous to describe, and reference), the group or team learning approach POGIL (Process Oriented Guided Inquiry Learning) has been documented as being effective for a variety of learners and has been shown to promote thinking and communication, among other skills in the sciences.[32–34]

This approach opens an avenue to enhance learning and may be especially beneficial for those who prefer personal interaction and for BLV students. Within this setting, each student is responsible for participating fully in activities, and students work collaboratively. In one framework where specific roles are assigned and definitive outcomes are expected (e.g., POGIL), each member of the group or team would have specific responsibilities and thus have an opportunity to be engaged; consequently, this fosters participation by individuals who have limited vision or are blind. The nature of the group interaction allows for students to receive assistance from each other and thereby place each in the role of teacher–learner. This type of collaborative work constitutes a high-impact practice that is encouraged by the American Association of Colleges and Universities.[35]

Group collaborative work is not limited to face-to-face settings; it may be simulated in online courses through breakout rooms and via the discussion board or other LMS tools such as Wikis. In group working environments, there is an opportunity for misconceptions, which are high among undergraduates, about persons who are blind or have limited vision to be dispelled and for there to be an experience of confidence-building for the student who is blind.[36] In this framework, students’ levels of self-reliance, self-direction, and independence—attributes that are of special importance when working in the instructional or workplace laboratory—can be enhanced.

PROMOTING INDEPENDENT WORK IN THE LABORATORY

Additional aims of this article are to provide college chemistry (science) faculty with an introduction to how laboratory work can be made accessible to BLV students and to illustrate how lab work can be carried out non-visually. Knowledge of and exposure to various types of adaptive/assistive technologies, scientific equipment, and instruments capable of providing an interface for the BLV student will enable lab instructors, technicians, and teaching assistants to prepare for interaction with students who make use of computer software and special devices to do their work non-visually. Lab assistants will then gain a more thorough understanding of the nature of the experiment and equipment, which can lead to better instruction for all.

For differently abled students, the primary goal is to enable them to become independent workers by providing access tools that will create the least-restrictive learning environment. Although the assistance of a directed laboratory aide (if BLV student requested) may be available for doing tasks such as reading procedures, equipment set up, manipulations, making observations, and notetaking, let us consider this an outmoded paradigm. It is possible to provide a more authentic and meaningful experience to a student who is blind where the student is wholly responsible for conducting manipulations and for recording data and notetaking. Therefore, the revised role of the laboratory aide would be for making visual observations *at the direction of the student* and as a safety consultant, placing the laboratory aide in a less intrusive role as an access assistant , not one who is responsible for performing the work. In circumstances when pairwise labs are performed, then cooperative/collaborative work is in order and the learning is accomplished jointly by the partners with distribution of workload; this is a valuable experience for the sighted student.

LAB WORK ACCESSIBILITY

It is worthwhile to highlight some of the tools that can transform lab work for the non-visual learner from a passive experience to an active one. Only general information about assistive/adaptive technology and hardware (by no means exhaustive), and function and basic operation are given. Experimental work accomplished by students with vision limitations can involve use of auditory and tactile input/output devices, such as phones with apps/cameras having audible output and tablets with touchscreens with speech output and voice-activation.

Laptop computer systems now include accessibility functionality (of note is Narrator and VoiceOver screen readers on Windows and OSX systems, respectively), thereby making them potentially suitable as accessible instrument interfaces for some state-of-the-science instructional equipment found in the undergraduate laboratory. Screen magnification and reading software installed on laptop computers or using a refreshable Braille display will enable BLV students to have portable real-time auditory or tactile access to laboratory information. Reading of lab procedures, data input and processing via the usual suite of products such as word-processing and spreadsheets should be the responsibility of the BLV student. Access to online simulations, databases (i.e., NIST WebBook) and journal interfaces that may be needed to supplement lab work in some cases may be problematic. Only by reporting limitations to the providers by students, faculty members, and institutions will circumstances change for BLV students. Intermediate ways of obtaining inaccessible information include through sharing by group members or obtaining it from faculty or through institutional disability services.

PREPARING FOR LAB

During the preparation and set-up phases for a lab session, whether it is for a verification or discovery-type experiment, the lab staff, including the directed lab aide or access assistant (if student requested), should become familiar with supplies and equipment, review the instructional approach, and discuss with the non-visual learner specific needs and how the work will be conducted with the minimum of assistance and operation of access/adaptive technology. Some useful information may be found in an American Chemical Society publication on teaching chemistry to disabled students.[37]

In conducting laboratory work, a variety of available devices can aid students in independently accomplishing manipulations. Notable examples are presented here:

- Electronic video magnifier that presents a high-resolution image of objects and text on a handheld screen, with color and contrast style settings; some are speech-enabled
- Braille-coded reagent bottles—with the use of a stylus and slate, BLV students can do their own labeling
- Bar coded or QR-coded reagent bottles can deliver detailed information
- Voice-recorded magnetic labeling can provide user comments
- “Talking” thermometers and balances
- Tactile calibrated volume dispensers
- Data-logging programs and computer interfaces enabled with speech output
- Instrument and probeware interfaces enabled with speech output

Adapting laboratory activities for BLV students can be accomplished without using extraordinary measures by being creative and utilizing common supplies and available technology resources.[38,39] Searching for publications in the literature may uncover valuable ideas and experimental alternatives. Recent reports of BLV-accessible lab experiments are limited, yet practical examples applicable to general chemistry and organic chemistry from the perspective of a blind person are available.[40,41] Assistive and adaptive modification of laboratory experiments that encompass the upper-level chemistry laboratory curriculum—for courses such as analytical and instrumental, inorganic, physical, and biochemistry—are not routinely found in the literature. It may be the case that experiments have been developed and used, but reports have not surfaced: there is no clearinghouse or convenient rapid route to dissemination of this type of work. A good source of information, with a useful list of references, addresses work in an advanced inorganic course by a BLV student.[42] When laboratory activities are being formulated or implemented, multi-sensory approaches should be included, and they should conform to universal design for learning guidelines and practices. Faculty are encouraged to make adaptations to existing seminal experiments in the upper-level chemistry curriculum and report this in the literature.

A general approach to making data acquisition and analysis available to BLV students is to combine screen reading technology with laboratory instrumentation and probeware. For example, the Sci-Voice Talking LabQuest device[43] announces data collection in real time as well as file menu and data table navigation. (A large selection of sensors is available to aid in making existing experiments accessible). With the JAWS-enabled Sci-Voice talking LoggerPro data collection software,[44] imported data is then available for statistical analysis and output in tactile and auditory form. As mentioned earlier, tactile representation (*e.g.*, Braille embossed graph) of graphical information can be used for analysis by BLV learners. Auditory representation of data through sonification[45] for exploratory purposes is becoming a significant aid and has been used for spectra analysis[46] and in the form of a free-standing tool.[47] More development work needs to be accomplished in this area.

IN THE LABORATORY

The non-visual learner can visit a live lab session to make "observations" and ask questions. Before the scheduled lab session, time should be allocated to have the non-visual learner explore the lab environment, experimental set-up, and equipment and to prepare and organize a workspace on their own (by touch). BLV students will follow safety procedures, including wearing of goggles. Their orientation and mobility training will enable them to navigate the lab and follow safety protocols. If a laboratory manual with raised-dot drawings generated by a Braille embosser is provided, BLV students can be made familiar with equipment, glassware, and set-ups beforehand. The benefit is that it can reduce the time needed by the student to accomplish the work during the regularly scheduled session and thus preclude the need to work during another lab session. A non-visual learner can arrange the materials and equipment as needed, test computer connections to devices and instruments and can do a "dry run" of the activity.

With the aid of a screen magnifier or reader, the student can access and operate instruments and perform data acquisition and analysis independently. As work is being done, notetaking is accomplished on a laptop computer by typing with the aid of a screen reading program or by speech-to-text software (although accuracy is limited, especially when mathematics and equations are being transcribed for future reference). With availability of the electronic lab notebook, the need to make handwritten entries into a paper notebook is eliminated and thus data recording may be handled independently by BLV students. Use of an electronic lab management system can promote class-wide participation in data collection and analysis. The generation of a lab report is a straightforward matter as access to word-processing, spreadsheet, "Talking" graphing calculators, and graphing programs are accessible as described earlier. When alternatives to in-laboratory activities (simulated experiments) are presented, where analytical and critical thinking and scientific and quantitative reasoning rather than hands-on skills are being learned or assessed, the simulation programs, videos and web-based content must be made accessible. With the advent of online lab experiments, the importance of providing alternative access to information is heightened.

IMPACT OF ACCESSIBLE CHEMISTRY INSTRUCTION

Prior to the beginning of a semester, we as undergraduate science faculty prepare an outline for each course by considering content and resources, learning objectives, and intended outcomes, instructional methods, and assessment tools. In preparing to teach a course we consider methods that will address the learning needs of our students. With knowledge and understanding of teaching approaches, instructional design practices, adaptive and assistive technologies and accommodations that are available to and used by the differently abled, and with the assistance of disability services, we can be more fully prepared to teach and help students achieve learning outcomes. For those learners having vision limitation or for those who are blind, chemistry (science) instruction can be made accessible with the techniques and devices described herein and thus make these students independent, especially in the laboratory. By integrating the diverse collection of learners in an active learning environment, we in the education community can make learning more effective for all and help dispel misconceptions about persons with blindness. If blind and low-vision students are fully engaged in the undergraduate science curriculum, it will increase their confidence, interest, and motivation, which will lead to entry into the science workforce by qualified, differently able scientists. Without conscientious efforts to make the undergraduate chemical sciences curriculum accessible, blind/ low-vision students will remain excluded from chemistry opportunities.

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