STEM for Students with Blindness and Visual Impairments:

Tenets of an Inclusive Classroom

by

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Tenants of an Inclusive Classroom

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This thesis is dedicated to:

My mom.
For showing me how one person
Can impact so many lives
And touch so many hearts
Just by teaching.
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Chapter 1: Introduction

Problem statement

Discrimination against students with disabilities in education is not a new concept. Until 1975, students with disabilities were not required to go to school and could be denied an education if the school district decided to do so. Currently this discrimination can still occur when students with a disability are advised against taking certain classes, especially in the STEM fields. For example, chemistry includes highly visual content and is paired with lab experiments that can cause a safety concern for students, teachers, and parents. As a result, a student with a blindness or visual impairment (BVI) may be told that they cannot take this subject. Students with disabilities could also be restricted to the classroom sections only and denied access to laboratory section participation.

Denying a student the opportunity to learn a subject through modified approaches in the hands-on part of an experiment can lead to a large underrepresentation in the chemical industry and workforce. According to the National Science Foundation, in 2008 only 6.5% of individuals in the United States had a disability (Wedler et al., 2014). Those with a BVI were an even smaller percentage within that workforce.

Significance of the problem

All students should have the opportunities to learn about something that interests them. Discriminating against students with disabilities because of the challenges presented to a district is a solvable problem through new learning methods and materials. There are many small technologies and adaptations that can be implemented into a classroom or a laboratory to a student with a disability to actively participate. Some of these technologies include
smartphones applications to help with titrations, the 3D printing of images or multiple different text-to-speech devices. Many of these technologies require further research into their accuracy and success rate, which can be tested by using larger testing groups. Beyond relying on just new technologies, a teacher can also implement smaller adaptations that can allow a student with BVI to participate in labs simply by modifying the structure of a lab, for instance: using tactile representations, picking labs that require the sense of smell, or performing an experiment within a plastic bag. These examples often require minimal costs and are simple to apply to an everyday classroom. Regardless of a student’s ability or disability, they should be allowed to pursue their interests and should not be denied the opportunity to pursue a career within a subject.

**Purpose**

Having a source of technologies and adaptations for a STEM classroom can be highly useful for a wide variety of parties, including educators, teachers for the blind, district or school administrators, students with BVI, and parents/guardians of those students. A compilation of these options allows a huge database of information to be in one location. Educators or teachers for the blind can use this resource to better support their students. General education teachers are more knowledgeable in the content area, while special educator teachers are more knowledgeable about students with disabilities specific needs. Closing the gap and bridging communication between both educator populations can create possibilities for learning and increased inclusivity.

Students themselves are often the most knowledgeable about the specific needs that they require in order to learn best. This database of educational tools and strategies could be an
excellent resource for students who have a strong passion for STEM learning. Both students with BVI and parents can use these technologies and adaptations, paired with the appropriate safety precautions, to fight for their right to actively participate in a science class and laboratories. By allowing these students the option to pursue their interest in STEM fields, a long-term effect would be an increase in the representation of individuals with disabilities in the STEM workforce.

**Rationale**

In order to increase the number of individuals with a BVI in the chemical industry and workforce, these students must have a strong interest in the subject; and this originates through involvement in chemistry labs. There are many access technologies available that enable a student the ability to actively participate in a STEM laboratory experiment. These technologies can help a student feel that they are included and part of the team; it also allows them to do the hands-on part of experiments rather than sitting on the side-line recording data or not participating at all (Supalo, Isaacson, & Lombardi, 2014). These technologies and adaptations often rely on the use of other senses, such as touch, hearing, or smell. Utilizing multiple senses can increase learning opportunities for all, while encouraging students with BVI to fully participate in a STEM class or lab. Technologies and adaptations can also help teachers feel prepared when they have students with a BVI in their STEM class. The more prepared the teacher feels, the more supported the students will feel as a result (Mumba, Banda, Chabalengula, & Dolenc, 2015).
Definition of terms

**Blindness and Visual Impairment (BVI)** – limited eyesight that cannot be corrected by eyewear; includes partial sight and blindness

**Technologies** – devices, software, or programs that are electronically used to support students with BVI

**Adaptations** – small changes or accommodations made in class or in a lab to support students with BVI

Summary

Having a resource with various technologies and adaptations can be highly beneficial for students and educators at all levels. It often occurs that a teacher will not discover the specific needs of his or her students until a week prior to the upcoming school year. Having a compilation of possible options to implement into the classroom could increase confidence, decrease frustration for the educator, and increase the opportunities for learning on the students’ side. The following literature review critically examines a multisensory approach to STEM learning and presents the various technologies and adaptations available for classroom and laboratory implementation.
Chapter 2: Literature Review

*Adaptations Using Tactile Representations*

Students with blindness and visual impairments are not able to learn STEM using the same inputs as other fully sighted students. The typical visual representations must be transformed utilizing a different sensory input so that the student can understand the concept being presented. One sensory input that can be used is tactile representations. The sense of touch is commonly used by students with BVI to understand the world around them, including within the classroom.

Pictures have a tendency to engage an individual more than words. Project 3D IMAGINE, or Image Arrays to Graphically Implement New Education, is a new software that allows students to use a tactile learning technique, presented in a raised 3D printed image, in order to more fully understand a STEM topic. As 3D printers become more common in schools, this technique becomes more readily available for both chemistry classrooms and classrooms in general. This new printing technique allows a student with BVI to interpret an image for themselves (Hasper et al., 2015); no longer needing to solely rely on someone else’s interpretation or description of educational images. Multiple materials have been tested to determine the best surfaces to 3D print images while incorporating Braille labeling further the intrigue of this product. Project 3D IMAGINE is an effective learning style converting tool that can be implemented into the classroom or lab. Countering the typical auditory learning style in many lecture settings, this technique is not only useful for students with BVI, but it can also be useful for able-bodied students, as it is just another way to process information (Hasper, et al., 2015). A 3D image draws an interest to the topic that is being taught. Striking
visuals can leave individuals wanting to know more and see more, while could lead to greater interests in a career in the topic.

Another tactile adaptation to learning a chemistry concept is reported by Stender et al. (2016) related to the metric system. For a standard chemistry curriculum, the metric system is relied upon. For students without the knowledge and general understand of how this measuring system works, many more complex concepts could be lost. The Metric System Activity (Stender et al, 2016) allows students to explore length scales, starting at a meter and dropping to a micrometer. A solid wood board with various tiles are presented to the student who would then touch the different textures of each tile. The variation of texture corresponds with the length of different metric units. Braille labels were included above each tile to create a fully stand-alone module. Results showed that the activity was successful in teaching individuals about the metric system and the differences in its units of length (Stender et al., 2016).

Hands-on activities have been shown to produce a higher level of learning, an increased interest in the content being presented, and an increase in participation from all involved. Various tactile representations and real-world examples allow students to feel the models and feel the reactions taking place further enhanced their learning process. Students with blindness or visual impairments (BVI) will not interact with the world around them in the same way a full sighted student would. Visual limitations may alter cause and effect understanding or may affect the relationships between people and objects; both can significantly change the way a student with BVI interprets the world around him or her. These students will need alternative ways, or course, adaptations in order to learn and problem solve. Being able to utilize other senses, such as touch, can increase interest in a subject and also greatly improve their learning outcomes (Kizilaslan, Sozbilir, & Zorluoglu, 2019).
In addition to chemistry concepts, full experiments can be done by students with BVI if simple accommodations are put in place. These adaptations can allow students with BVI to be involved with the experience of the experiments take place. In the fermentation process of ethanol generation, students can lift the flasks periodically in order to hear, feel, and smell the bubbles form and exit. For endo- and exothermic processes, the solutions were put into plastic bags so that students could feel the temperature change of reaction. This “baggies experiment” method can also be useful for acid-base reactions. These bags let students feel any macroscopic changes that occur, while using their sense of touch (Wedler et al., 2014).

Four additional inexpensive laboratory activities have been designed that can be utilized in an informal setting; allowing students with blindness and visual impairments the ability to actively participate in hands-on laboratory activities. These four modules include the Sound and Feel of Data, the Conductivity of Materials, Optical Lenses, and the Chemistry and Physics of Heat. All four modules utilize a tactile representation of the key concept being presented. According to results, all described laboratory modules showed to be successful at informing individuals about their desired STEM concepts (Kumar et al., 2018).

The Sound and Feels of Data module converts visual signals into tactile and audible ones. Because data is typically presented in graphical or visual representations, it can be difficult for individuals with blindness or visual impairments to interpret it. Interpreting data is key to revealing phenomena present. This module used pipe cleaners and coins as the x- and y-axis and the trend line or curve, respectively. Individuals could feel the linear trendline or parabolic curve that is in front of them. In addition, the demonstrator utilized a smartphone sound app. He or she would activate a higher note and the participant touched a higher point on the graph. Lower points would be associated with lower notes. By feeling and hearing the different trends,
individuals can begin to categorize the different styles of data representations (Kumar et al., 2018).

The Conductivity of Materials module utilized a wooden box filled with marble to symbolize a metal, a semiconductor, and an insulator. The marbles represent electrons and how they would flow within each of the materials. The metal had free flowing marbles that were not pinned down, provided the highest conductivity. The semiconductor had the marbles on top of bubble wrap, slowing the marbles down as they moved around the box. The insulator had the marbles glued to the base of the box, not allowing them to move at all. As the participants learned from these examples, the demonstrator then hooked up everyday items to a circuit that would produce a noise. The participants would have to determine, based on the sound produced, which material it might be made of (Kumar et al., 2018).

Participants responded strongly to the Optical Lenses module because of the connection with the human eye. The lenses presented in the module includes a convex focusing lens, a concave diverging lens, and an astigmatic semi-convex lens. All three lenses were presented by attaching a curved plastic piece and string to a corkboard. The string is set up in the way that the light or visual images would be directed, based on the lens. This module allows for exploration in a tactile manner (Kumar et al., 2018).

Kumar et al. (2018) fourth module is the Chemistry and Physics of Heat was the final new module in the research article. Participants were taught about the flow of heat and energy through exothermic and endothermic reactions. Tubes of ammonium nitrate and sodium sulfate were given to participants. Given agitation, the reaction would take place, getting warmer or cooler dependent upon the reaction type. A second experiment, where supersaturated sodium acetate solution, commonly known as a hot pack, was given. Agitating a metal piece within
the pack set off the reaction, producing heat and changing the consistency of the solution within
the hot pack. In both experiments in this module, participants were able to feel the changes
taking place based on the temperature change of the reaction (Kumar et al., 2018).

Writing and balancing equations is typically taught with visual representations to explain
the concept, with figures within the textbook, example problems on the front board, or lecture
notes. All of these methods create a problem for a student with blindness or low vision. Even
lecture notes did not translate well using a text-to-speech function because of the subscripts
and superscripts. Boyd-Kimball (2012), utilized magnetic letters and numbers that could be
shaped like a standard number or labeled with Braille when it came to writing single
compounds. These magnets were used to show positioning of atoms and subscripts in exchange
for a visual representation. For full reactions and balancing equations, smaller magnetic pieces
with puffy painted letters and numbers could be inserted to save space. Using the raised letters
or Braille letters allows the student to identify the particular atom independently (Boyd-
Kimball, 2012).

Singhal and Balaji (2020) report on a lock and key model for molecular representations to
assist in forming chemical compounds as well as writing and balancing chemical equations.
The goal of this tactile creation is to introduce and familiarize students with BVI with chemical
symbols and notions, such as plus and minus charges, superscripts, and subscripts, all in hopes
to better understand balancing a chemical reaction. The large puzzle pieces consist of chemical
elements, arrows, symbols, or numbers. This includes forward, backwards, and reversible
arrows and both parenthesis and brackets for formula writing. The smaller puzzle pieces are
half the size and consist of numbers for superscripts and subscripts and symbols, such as plus
or minus signs for ions. All pieces include the conventional alphanumeric letters and Braille
labels to enable both sighted and non-sighted students to learn side by side. The Braille labeling is in accordance with the required spacing of the National Library Service. Applications for this tactile adaptation include ionic representations, molecular representations, and chemical equations (Singhal & Balaji, 2020).

Adaptations Using Auditory Representations

Another sensory input that can assist students with blindness and visual impairments are auditory representations. Concepts typically taught or displayed in a visual fashion can be transformed into sonified information, allowing students with BVI the ability to fully participate in activities and to collaborate with their peers; creating a more inclusive classroom. Auditory representations can be used in a specific manner for activities or they can be used in a more general fashion, casually used throughout a lecture or lesson.

Demonstrations are a useful tool to show students some of the interesting applications of STEM concepts they learn in class. A standard teacher demonstration that is done in most chemistry is creating an electrochemical cell to produce energy. In the past, this electrochemical cell could be used to ignite a light bulb or produce a monotone buzzer. At strong amounts of electrical current running through the circuit, the light would be brighter, or the buzzer would be louder. A twist on this standard demonstration is to bring in the engaging factor of using music. Instead of a monotone buzzer, a song could be played. The song would decrease in volume and drop in tempo as the cell approached its power failure. Cady (2014) reports that students who have participated in this modification of the typical electrochemical cell often smile and some will even sing along with the tune. Utilizing a music greeting card is a simple way to produce a song that has already been programmed. This modification can
be especially useful for students with blindness or visual impairments because of the unique auditory aspect, as opposed to the visual representation when a light bulb is used (Cady, 2014).

Cady (2014) reports three variations of the electrochemical cells. These “homemade” batteries include using a Zn/Cu (II) cell, a Zn/H+ lemon battery, and a solar panel. All three batteries include the use of the music generator and can be easily implemented into a classroom lesson. From a safety standpoint, all three of these demonstrations do not produce enough voltage too be dangerous. However, it is important to use appropriate eye protection and go through with proper hazardous waste disposal when needed (Cady, 2014).

The electromagnetic spectrum is another visual concept learned in most chemistry classes. Stender et al. (2016) reports an auditory approach to learning about the electromagnetic spectrum. An acoustic frequency change was used to indicate a change in wavelength. It is important to note that although these modules are specifically designed for students with BVI, students of all abilities can benefit from a multisensory approach to learning. These modules can also promote an inclusive learning environment allowing students with disabilities and general education students to collaborate and learn from the same materials simultaneously (Stender et al., 2016).

Interpersonal communication and student feedback are also crucial to help students with BVI increase self-efficacy and learn in their STEM classes. When deciding between verbal descriptions versus tactile representations, it is highly dependent on the student’s capability to mentally manipulate special relationships and verbal descriptions. In a specific case reported by Miecznikowski, Guberman-Pfeffer, & Donaruma (2015), the participant had a strong prior knowledge background and a high ability to visually create images from verbal descriptions. Therefore, verbal descriptions were used whenever possible. One general rule when giving
verbal descriptions is to avoid terms such as “this, that, here, there” given their directional nature. Recommendations include first describing the overall shape of the structure, numbering corners or sides of the molecule, and having the student draw the structure in the air to ensure he or she is comprehending the verbal descriptions (Miecznikowski, Guberman-Pfeffer, & Donaruma, 2015).

**Technologies for a STEM Laboratory**

As technology becomes more prevalent in today’s society and today’s classrooms, it is important that the possible supports provided to students, keep up with these changes. Technologies can be useful in transforming a visual images or observations into tactile or auditory representations, allowing a student with a BVI to understand the information being presented to them. Chemistry laboratories are especially visual and often need observations in order to interpret data and understand the experiment. Students with BVI are often designated as the group member to record notes and are not actively participating in the experiment. Various technologies can encourage more independence in the laboratory and engage these students in the subject.

The Titration ColorCam is an Android-based smartphone application to assist color-blind and visually impaired chemistry students with titration experiments (Bandyopadhyay & Rathod, 2017). This application uses the camera of a smartphone to detect changes in the color components (hue, saturation, value) of a solution. The app then signals these changes via audio (beep sounds) and tactile (device vibration) notification. As the student gets closer to the equivalence point, or end point, the number of beeps begins to increase, telling the student to slow down the addition rate of the titrant. Once the equivalence point is reached and the
titration is completed, the device will produce a continuous sound and a prolonged vibration (Bandyopadhyay & Rathod, 2017). The Titration ColorCam can also be used by a student with full sight simultaneously encouraging collaboration between students with BVI and students with full sight, while producing an inclusive environment.

Another laboratory application that can assist students with BVI to fully participate in chemistry labs is the accessibility thermometer. This support is a digital thermometer that will inform the user of the temperature through a digital reading as well as through beeps and vibrations. A sensor is attached to the reading device via wires. The section of the probe that gets submerged in the solution is enclosed in a glass tube. Due to the structure of the thermometer, the entire bottom piece of the sensor must be completely submerged to get an accurate reading. This accessible thermometer is designed for students with visual impairments or other disabilities, however, can be utilized by all students. The device can measure temperatures from -15°C to 115°C, making this range very useful for high school and higher education laboratories (Vitoriano, Teles, Rizzatti, & de Lima, 2016).

Two modes are included in this accessible thermometer. The first is a “set point” mode, where the device measures the temperatures within a chosen range. Once in this range, the device will simultaneously produce beeping and vibrations. The second is a “numeric indicator” mode, where the actual temperature of a solution is measured. The device will emit beeps and vibrations in a certain sequence, much like Morse code, to indicate the value of the temperature. Vitoriano et al. (2016) conducted multiple tests for this accessible thermometer against to two standard thermometers and found it was highly correlated in reporting accuracy to both (r>0.97). Students with BVI were surveyed after using the accessible thermometer and they stated that it was very helpful but could take some getting used to (Vitoriano et al., 2016).
The sonified infrared spectra (SIRS) is a technology that can be implemented into a higher education chemistry laboratory. SIRS converts a graphical representation of an IR spectra into nonspeech audio sounds, allowing students with BVI the ability to interpret the data for themselves. This method is a straightforward and inexpensive alternative to tactile graphs or tabular data. The SIRS correlates the frequency of a musical instrument with the intensity of the absorption bands on the IR spectra. In addition, time markers at 3000, 2500, 2000, 1500, 1000 cm\(^{-1}\), and the end are included to allow the user to identify the location of the bands more quickly. In order to successfully use this technology, audio training is recommended in order to familiarize the student with the process of identification. Organic molecules with single functional groups were used to train students to better understand the changes in frequency and the time markers within the SIRS technology (Pereira et al., 2013).

The overall goal of the SIRS technology is to allow students with BVI the capability to identify the main functional groups on an organic molecule. The participants in this study had positive opinions on SIRS, but some felt it was too complex compared to tactile graphs; and required more training (Pereira et al., 2013). SIRS provide students, professors, or other individuals in the workforce the ability to read IR spectra with other bodily senses and without assistance. This technique could also be useful for sighted students, as multisensory learning can lead to a better academic retention and a greater learning curve (Pereira et al., 2013).

An additional assistive technology that can be used within a STEM lab is the SciVoice Talking LabQuest. This hand-held device has an on-board computer with a touch screen. The SciVoice Talking LabQuest can collect, store, and graph data with the various probes and sensors that can attach to the device. Some attachments include a temperature probe, a pH sensor, a drop counter, a gas pressure sensor, a light sensor, and a colorimeter It also has
additional probes that can attached to the device to obtain data collection (Kroes, Lefler, Schmitt, & Supalo, 2016). The most important thing about this device is that it includes a text-to-speech application, which creates opportunity for students with BVI to do experiments and collect data independently (Supalo, Isaacson, & Lombardi, 2014; Supalo, Hill, & Larrick, 2014).

Various common laboratory experiments can be slightly modified to include the SciVoice Talking LabQuest, therefore making a more accessible environment for all. These labs include a Pressure Syringe Lab, an Acid and Base Titration, and an Endo/Exothermic Reaction Lab (Kroes et al., 2016).

**Technologies for a STEM Classroom**

Similar to a STEM laboratory, much of the concepts in STEM lecture are shown and taught in a visual manner. This is problematic for students who have blindness or visual impairments (BVI). The visual nature of STEM has prevented individuals with blindness and visual impairments (BVI) to integrate into and pursue the general curriculum. Inclusive classrooms only work at building a sense of quality if equity is also a part of the classroom instruction. Each student must get what they need in order to succeed. For a student with BVI, diagrams, charts, and lab exploration need to be portrayed in a different way. Visual images need to be converted to tactile representations or verbal descriptions. The Next Generation Science Standards suggest course modifications such as presenting materials in Braille, using audio files, and using tactile images and materials. New technologies are adding to these opportunities for equitable learning.
The visual based textbook and labs make it difficult to process the information that students with BVI are given. However, by using an audio format learning style, learning new information is easier and more effective. Kamijo et al. (2016) created a prototype called Chemical Literature Extraction and Aloud-reading System (CLEArS). This software can separate text and images of chemical compounds from a page and then read both the text and the name of that chemical compound aloud (Kamijo et al., 2016).

The CLEArS software will take a page from a textbook or an article and differentiate between the areas of text and the areas that an image is located by looking at the density of pixels. This process allows for the software to read the text aloud to the user without confusing the areas where a chemical compound is located. The research team tested this aspect of the software using both articles from published academic papers, including complicated structures, and pages from a high school textbook, including less complicated structures. The success rate of the academic papers was 89.2% and the success rate of the textbook was 96.1%. Averaging the two data, with regards to the number of pages from each source, the average success rate for differentiating between text and images was 90.0%. The next aspect that was tested was if the software could then correctly identify and name the compounds that were on these pages. The academic paper has a 48.3% success rate and the textbook pages had a success rate of 56.9%.

CLEArS can be utilized in higher education allowing students with BVI who have an interest in chemistry the ability to pursue their careers with this assistive technology. These students will be able to independently study and learn about compounds. There is also potential that this software will encourage the development of similar technologies within other fields, creating even more possibilities for students with disabilities (Kamijo et al., 2016).
Another software to assist in learning about molecular structures was created to enable the communication and the interpretation of molecular structures and reactions. NavMol 3.0 software utilizes cheminformatics to automatically identify molecular structures and voice synthesizers to read information. The free version NavMol 3.0 software allows users to load premade molecules from files and then jump from atom to atom through bonds, gaining information about each atom, their neighbors, and their bonds. This process of atom mapping is audibly announced to the user upon request. For metabolic reactions, the user can also jump from the reactant atom to the corresponding product atom, which allows the student to interpret the changes occurring from a structure standpoint. Students and other users are able to edit molecular structures within the software. Binev et al. (2018) reports on using standard reaction templates for students to build off of and create the desired reaction. If a fragment of the reactant is changed, the software will automatically change the corresponding site on the product molecule. Fragment templates have also been created to make easier editing access for all students, but especially for students with BVI. A multisensory approach to highly complex processes gives any student or professor the ability to benefit from this software in a STEM lab (Binev et al., 2018).

A software model, Listening-to-Complexity (L2C), was created to assist students with BVI in learning highly visual chemistry concepts. It was based on the original sonified NetLogo model (Levy & Lahav, 2012). L2C models transform visual information into sonified information, or non-speech audio. These computer based L2C models utilize hands-on exploration of STEM learning for participants (Lahav, Hagab, Talis, & Levy, 2019).

In one research study, Levy and Lahav (2012) explore the phenomenon of inflating a bicycle tire to engage students and teach how gases move in different spaces. Instructions,
explanations, and questions were prerecorded in order to allow more independence of the user. The L2C model will give the users real-time feedback as molecules are moving around the space. This movement could include increasing or decreasing velocity, changing location, or interacting with other objects or molecules. Both collision with walls and collisions with other gas particles were included for this exploratory experiment. Various sound patterns were associated with the different movements and interactions, allowing the L2C system to deal with the rapidly changing complex gas particles, while still providing feedback. Levy and Lahav (2012) noted that the sonification process, or the presentation of information using nonspeech sound, was most effective when there were three or less audio channels occurring at the same time and if there was a greater frequency separation between sound streams. These distinct sound changes will allow the users with BVI to better interpret the movement of the gas particles (Levy & Lahav, 2012).

Mobile-learning tools are on the rise as advanced computing technology becomes more available in today’s classroom. Technology has the unique possibility to allow students who have disabilities to actively participate in all aspects of the classroom. Quick response (QR) codes are a simple technologic aid that can provide unlimited opportunities for learning to all students. The QR coded audio version of the Periodic Table of Elements (QR-APTE) for a chemistry classroom is specifically designed to assist students with blindness or visual impairments. Although the periodic table is available in many forms, including the classic paper form and the modern interactive form, many of these are not useful for a student with impaired vision. Much of the chemical information about each element is lost. Contrary to using Braille to read about the elements and their chemical information, the QR-APTE was invented (Bonifácio, 2012).
The software ChemDraw, allows students to form molecular structures. With recent updates, it now has the ability to add Braille labeled elements within the organic molecule. Other structures can also be found on the online portion of the software. This function also allows the font to be changed to Braille. The image can then be printed onto a Picture in a Flash (PIAF) capillary paper. The PIAF technology device can then raise the ink that has been printed onto the paper, producing a tactile image. What sets this technology apart from others is the attention to detail for dot specifications in the Braille writing. The spacing of the Braille font in ChemDraw meets the National Library Service’s requirements (Supalo & Kennedy, 2014).

The BrailleNote and the Brailler are also technologies that can be used to complete conversions and calculations. The BrailleNote is a computer device that can open and read documents, do calculations, and do electronic typing in Braille. The small display screen of the device only allowed a small section of text to be displayed at once. This created difficulty when scrolling through to find a specific section of text. Harshman, Bretz, and Yezierski (2013) report that this device can be frustrating for a user to complete math problems and recommend the Brailler. The Brailler is a nonelectronic typewriter that types in Braille on special paper. This support allows the user to see everything at once, which can lead to a more accessible and searchable space.

**Stakeholders Impact and Responsibilities**

Open communication is important for the success of all students, but especially for students with disabilities. Each of these students have specific individual needs that a general education teacher may not be experienced with. This additional component of a science classroom can create an even larger stress for teacher if they are not educated on available
technologies and adaptations for a truly inclusive classroom. This responsibility then falls on the special education teacher. However, at the high school level, disciplines become more specific and it is less likely that the special education teacher is trained in that specific field. Having a resource with a compilation of technologies and adaptations for students with BVI begins to bridge the gap between these two parties, and results in tremendous benefits for the student. This information could also be highly beneficial for administrators and districts. It is important that they understand the available supports for all students in order to create an inclusive environment for all (Mumba et al., 2015).

When effectively implemented, open communication can also create valuable experience for both teachers and students. Students with BVI or other disabilities tend to be very knowledgeable and create about their specific needs, which can help teachers create course adaptations to help them. In addition, by having a student who has specific needs, teachers are forced to reflect on their own materials or their own instruction style. This reflection will only lead to enhancements in the content being present. Having multiple modes of learning in a clear concise fashion will benefit all students and the teacher. Multisensory presentation of STEM concepts will be beneficial for everyone involved. This growth starts with open communication between students and the teacher. It is also dependent on the teacher’s willingness to change and grow for the benefit of the students. It is often not about which technique works best for the teacher, but which technique works best for the students (Supalo, 2016).

Another area of improved communication that would impact the use of available technologies and adaptations for students with disabilities is the communication between the access technology industry and the science education technology platforms. This lack of
communication created a cyclic down spiral in terms of representation of individuals with disabilities in STEM career fields. Without individuals in STEM fields to speak up for others like them, it is less likely that technology will be more accessible, which then leads to less individuals in the STEM fields. Open communication between these two parties will help eliminate the problem (Supalo, 2016).

Safety and Implementing New Technologies for Students with BVI

Maintaining a safe laboratory environment is a leading concern in any STEM educational setting. The implementation of each technology and adaptations it creates should also be considered with input from the appropriate resource, such as the special education teacher, the general education teacher, or an administrator. It is imperative that both the teacher and the student feel comfortable and safe implementing the strategy. Harshman, Bretz, and Yezierski (2013) recommend a discussion or a separate meeting with all stakeholders takes place to go over how a technology or adaption will run prior to using it during a lab or in the classroom. This will increase the likelihood of the activities success and increase the safety of everyone in the classroom (Harshman, Bretz, & Yezierski, 2013).
Chapter 3: Project

The following project is a compilation of different adaptations and technologies that can be implemented in a STEM classroom to assist students with BVI. Teachers can refer to this resource when inspiration is needed. All resources include a title and which STEM field they might be most useful in. This does not limit each resource to that specific discipline; creativity can be applied wherever found. Each resource also includes the major purpose, what sense it utilizes, and the supplies needed. Included for each resource is a rationale for how each can benefit a student who is blind (Student A), a student who has a visual impairment (Student B), and a student with full sight (Student C). Recommendations for best classroom or laboratory implementation are provided, as well as any limitations this resource cannot provide.
Adaptations Using Tactile Representations
The “Baggie Experiment” Method
Chemistry: Heat & Kinetics

Purpose:

The “baggie experiment” method allows students with BVI to feel the macroscopic changes of a chemical experiment. Temperature changes will indicate if an endothermic or exothermic reaction as occurred, while fizzing can indicate when the reaction is in progress and completed. Utilizing the sense of hearing and touch create a more accessible environment for students when learning about chemical reactions.

Sense Used: Hearing & Touch

Supplies Needed:

- Plastic zip lock bags
- Water
- Ammonium chloride/ Calcium chloride/ Citric acid & Sodium bicarbonate
  (reaction depending – see rationale)

Rationale and examples:

Observations for chemistry experiments often rely solely on sight. For safety purposes, chemicals cannot usually be touched with bare hands. However, in introductory level chemistry classes, some experiments can be conducted within a plastic zip lock bag. The bag acts as a barrier, allowing the user to feel any changes in temperature. Endothermic and exothermic reactions can be identified based on the temperature change within the bag. Three possible reactions to implement into a classroom are provided below. In order to know when the following reactions are completed, the fizzing will cease and the contents can be disposed of properly (Wedler et al., 2014).
Figure 1. A student participates in a “baggie experiment” and makes observations through tactile methods.

**Baggie Experiment 1: Dissolving ammonium chloride in water**

This experiment is a great introduction to transferring energy and is similar to what would be seen in a standard cold pack, making a real-world connection. For this reaction, about 15-20g of NH₄Cl is combined with 20mL of water within the plastic bag. The bag should be sealed before or just as the substances are mixed. The reaction should absorb 14.8 kJ/mole. The temperature change will indicate an endothermic reaction.

**Baggie Experiment 2: Calcium chloride in water**

This experiment is an exothermic process and therefore releases heat. The temperature change can be felt through the sides of the bag. For this experiment, about 5g of CaCl₂ is combined with about 10mL of water. Proportions can be varied to determine the optimal ratio.

**Baggie Experiment 3: Citric acid, sodium bicarbonate, and water**
In this reaction a carbon dioxide gas is produced as citric acid undergoes the reaction, inflating the bag. To start, 1g of citric acid and 1g of sodium bicarbonate will be added to the bag, followed by the addition of 20mL of water. It is important to remove as much air in the bag as possible before adding the water, to exaggerate the production of CO$_2$ gas. Ratios can be changed in order to touch upon the stochiometric ratio of the reaction and to find the ideal reactant amounts.

Student A, who is fully blind, would be able to participate and make independent observations in any of these three experiment adaptations. Student B, who has a visual impairment, can rely on multiple different senses other than sight to make observations and inferences about the reaction taking place. Student C, who is fully sighted, this multisensory approach to microscopic changes within a reaction can help this student make inferences about what is occurring within the reaction. Using the “baggie experiment” method, all students can make observations and inferences about chemical reactions that they would not have safely been able to do, creating a more engaging classroom.

**Recommendations:**

It is recommended that the cup of water is placed into the bag without being poured in initially. Once the bag is sealed, the cup can be flipped mixing the water and the chemicals. This will help present air flowing in and out of the bag and will maximize the effects of the reaction. This can also prevent spillage of water or chemicals while tactile observations are being made. It is also possible for variables of each reaction to be altered to see how it would change the results of the reaction, creating a more inquiry-based assignment.

**Possible Limitations:**

The major limiting factor of this method is that not all chemical reactions can take place in a plastic bag. Some chemicals will break down the plastic and could cause an unsafe environment for students and others in the room. Beakers could be an alternative, but it would be less effective for feeling the chemicals dissolve or fizz.
The Chemistry and Physics of Heat

Chemistry: Heat and Physics

**Purpose:**

The Chemistry and Physics of Heat activity allows students to safely experience changes in temperature due to physical changes or chemical reactions. This can easily be implemented into any classroom because temperature change does not heavily rely on a visual aid. Students with BVI can benefit from this activity right alongside their classmates.

**Sense Used:** Touch

**Supplies Needed:**

- Ammonium nitrate
- Sodium sulfate
- Water
- Hot pack with sodium acetate and metal strip (optional)

**Rationale and examples:**

The difference between endothermic and exothermic reactions are a commonly covered topic in an introductory chemistry course. This activity lets students feel how the temperature of the environment around the reaction changes based on the type of reaction that occurs. First, two plastic vials with ammonium nitrate and sodium sulfate and given to students. Water will be added into each vial, capped, and lightly shaken. The vial with ammonium nitrate should get colder, indicating an endothermic reaction. Energy is absorbed from its surroundings in order to break the strong ionic bonds within the chemical. The vial with the sodium sulfate will get warmer, indicating that it is an exothermic reaction. Energy is released into the surroundings in the form of heat. A second part to this activity involves a hot pack with supersaturated sodium acetate and a metal device inside of it. If the metal piece is bent, the crystal seeds within it produce heat, warming the hot pack and initiating crystallization. This is a real-world application for the concepts being learned in the classroom setting (Kumar et al., 2018).
Because temperature changes are not something that can be seen by anybody, students of all sight abilities can benefit from this activity. Student A, who is blind, Student B, who has a visual impairment, and Student C, who has full sight, can all work together to feel the change in temperature for endothermic and exothermic reactions. For this type of experiment, a tactile observation is the ideal method to make observations and inferences based on the temperature. The Chemistry and Physics of Heat activity promotes inclusion in the classroom, as all students complete this activity together and in the same fashion.

**Recommendations:**

It is recommended that the two plastic vials being used are labeled in order to not confuse the two white powders. Providing a data sheet or a place to record observations would also be a useful resource for students. This activity could easily be turned into a short laboratory experiment and the teacher could assign a lab report, if desired.

**Possible Limitations:**

The large step between the first part of this activity with the vials and the second part with the hot pack and be confusing for students that are new to chemistry or physics. The concept of crystallization and lattice structures may not have been covered, or may not be covered at all, in the course. This deeper understanding behind how a hot pack works would be lost if this is the case.
Conductivity of Materials
Chemistry: Heat & Physics

Purpose:
The Conductivity of Materials activity introduces the idea of conductivity and electronic behavior in conductors, semiconductors, and insulators. Tactile representations are initially used to simulate the movement of electrons within materials using marbles in a wooden box. In addition, current can also be converted into sound and the conductivity of different materials can be explored with audio. This activity was originally designed for students with BVI in a STEM classroom, however because electrons are not visible these marble models are an asset to any classroom.

Sense Used: Hearing & Touch

Supplies Needed:
- 3 wooden boxes
- Marbles
- Bubble wrap
- Glue

Rationale and examples:
A material’s ability to conduct electricity relies on the ability of the electrons within the material to flow freely. Electron flow is an invisible phenomenon to all, therefore having an analogy to help students learn about this concept is highly recommended. Kumar et al. (2018) created an activity for students with BVI that uses the sense of touch and the sense of hearing to help simplify this complex concept. Three wooden boxes are placed side by side on a table all containing marbles. The first box has nothing but the marbles, that have the ability to move freely, much like the electrons in a conductor. The second box has bubble wrap underneath the marbles preventing them from rolling as easily, similar to how electrons would move in a semiconductor. The third box is coated with a thick layer of glue that the marbles are stuck in, unable to move. This box represents an insulator where electrons cannot flow freely, and electricity is not able to flow through the material. Students are able to explore these three
boxes and descriptions are given throughout the module. A professor or demonstrator would be needed to provide these descriptions.

A secondary piece to the activity is converting current into sound. A simple circuit with a buzzer or speaker is used to produce an audio representation of the electrical current flowing. First, the circuit is closed and the noise is projected as a baseline for students. Then a screw (conductor), a piece of Si (semiconductor), and a piece of glass (insulator), were placed into the circuit with alligator clips. The audio sounds varied depending on which material was placed within the circuit, further teaching the student about the conductivity of materials (Kumar et al., 2018).

![Image of three wooden boxes labeled Metal, Semiconductor, and Insulator](image1.png)

**Figure 3.** Above, the three wooden boxes are shown with the necessary materials within, representing a metal, a semiconductor, and an insulator. Below, a participant is completing the activity while the demonstrator plays the sounds from the circuit.
This activity would be beneficial for all students, but especially for a student with BVI. For Student A, who is blind, these tactile and auditory representations are crucial for the comprehension of electrons moving within a material. This complex concept is not easily understood without an analogy or visual. For Student B, who has a visual impairment, this multisensory approach to a complex concept can increase initial understanding. For a student with full sight, such as Student C, this activity is still very useful because of the invisible nature of electrons. Both the tactile and audio resource would be used by all students, promoting inclusivity in the classroom.

**Recommendations:**

It is recommended that a professor or demonstrator be present during the activity to help explain how the marbles represent electrons and redirect any misconceptions as exploration occurs. This activity might be best used in a small group or stations environment. Finally, it is recommended that during the second part of the Conductivity of Materials activity, students have access to the wooden boxes to help them make connections while listening to the audio.

**Possible Limitations:**

The Conductivity of Materials activity needs a professor or demonstrator to explain the deeper concepts; this person may not be available for all groups at once. A second limitations is that students may also need to have some prior background knowledge about how some materials hold heat better than others.
Fermentation Experiment
Chemistry: Organic

Purpose:
The Fermentation experiment is an alternative approach to generate ethanol using sugar and brewer’s yeast. Participants can utilize multiple senses in order to make observations and track the progress of the reaction. This multisensory approach can increase collaboration between all students, but especially benefit students with BVI.

Sense Used: Hearing & Smell & Touch

Supplies Needed:
- Sugar
- Brewer’s yeast
- Deionized water
- Fermentation, vacuum filtration, and distillation set up

Rationale and examples:
Ethanol generation can be accomplished by the reaction between sugar (or corn sugar) and brewer’s yeast. First, sugar should be dissolved in 250mL of deionized water within an Erlenmeyer flask. Yeast powder should then be added to the sugar solution and swirled within the flask. Once the solution is prepared, the two-hole rubber stopper should be placed on top of the flask. One hole is covered with parafilm and the second is capped with a fermentation lock. The fermentation process needs 72 hours to proceed. However, throughout this process, students can make observations by hearing bubbles form and pop, smelling by wafting, or touching the sides of the flask. After the 72-hour period, the solutions should be filtered through diatomaceous earth using vacuum filtration. It might be useful to let students explore the glassware and the setup prior to operating the filtration system. Students can feel the volume decreases as the filtration process is ongoing. The filtrate will then undergo distillation to obtain the ethanol. Wedler et al. (2014) notes that this ethanol can be diluted and used to power an ethanol fan if an ethanol fuel cell is used; this could be a great application post experiment to show how ethanol generation can be used in a real-world application.
Student A, who is fully blind, this experiment would enable full participation because of the various senses used to track the reaction. This student can make independent observations and rely on both touch, smell, and hearing. Student B, who has a visual impairment can benefit from this experiment similarly to how Student A would. If Student B has some sight ability, this is yet another sense that can be used to make observations. For a student with full sight, Student C, he or she has the opportunity to use 4 out of 5 senses when completing this experiment. Collaboration among all students is also possible.

**Figure 4.** (A) The fermentation set up is shown with the solution in an Erlenmeyer flask with a two-hole stopper. One hole is covered with parafilm, the second has a fermentation lock. (B) Changes in smell can be exaggerated by placing a wafting fan in front of the reaction occurring. This provides a safe way to make observations by smell without getting too close to the beaker or flask.
**Recommendations:**

If any steps cannot be completed by the students in the interest of time or safety, it is recommended to have an example set up of the glassware that will be used for the step done behind the scenes. This will allow the students to tactile observe the process, while remaining safe and staying within the time limit of class.

**Possible Limitations:**

Fermentation requires a multi-day process, meaning that the extended time could be a limiting factor for the application of the experiment in the classroom. Students may not be in the classroom consecutive days, or class time might not be able to be designated solely to this experiment. In addition, working with glassware and chemicals can pose a safety concern for any chemistry teacher. Proper safety measures must be taking before, during, and after the fermentation process.
Magnet Chemistry
Chemistry: Bonding & Formula Writing

Purpose:
Magnet numbers and letters can be used to explain bonding between elements with Lewis dot structures and create balanced chemical reactions. Typically taught using visual aids, these concepts can be taught with a tactile aid in order to assist students with BVI in a chemistry classroom. The simplicity of the materials allows multiple uses throughout various units. Pieces are easy to move around on the magnetic board, therefore mistakes can easily be corrected and worked through, encouraging a growth mindset for all students.

Sense Used: Touch

Supplies Needed:
- Large magnetic board
- Magnet numbers, letters, bonds, and special characters (i.e. +, →, e⁻, ·)
- Puffy paint (optional)

Rationale and examples:
Using magnets to portray letters, numbers, and special characters can be a useful tool in many units within a chemistry course. Letters can be used as elements, numbers can be used as subscripts, coefficients, or charges, special characters can be used in differing reactions or in Lewis dot structures. Possible units include, but are not limited to, organic, redox, and acids and bases. Magnets allow students the ability to easily move around and reuse pieces while feeling what letter, number, or character is selected. All magnets would be placed on a large magnetic board that can be placed on the student’s desk. Needed magnets can be supplied by the professor. How a student might use these magnets to complete a balancing problem is shown in Figure 5. Special characters can also be used to create Lewis dot structures and explain how bonds are formed. In Figure 6, two dots are replaced with a bond (Boyd-Kimball, 2012).
Figure 5. The chemical reaction is balanced by a student using magnet letters and numbers. What would be seen on a work page is included on the left, while the magnet work is included on the right. Both images are exactly the same in content.

For a student who is blind, such as Student A, magnets could be used if Student A had knowledge of the shape of letters or numbers in the English language and not in Braille. An alternative is to provide Braille labeled letters and numbers on magnets; just as puffy painted letters would be included on them. Working with the same supplies for multiple different units can help the student feel familiar and comfortable using the magnets as well. For a student with a visual impairment, such as Student B, a secondary sense could be relied upon when working through problems. For a student who has full sight, such as Student C, this magnet learning presents a new, fun way to learn about chemistry concepts, it includes a multisensory approach, and it promotes a growth mindset by encouraging corrections and working through problems. In addition, it also keeps a student’s paper much cleaner because the amount of crossing out or erasing decreases.

Recommendations:

If additional letters or characters are needed, plain magnets can be painted with puffy paint to create a raised letter on the magnet. This would be highly useful for common elements like Carbon or Oxygen, especially if used in an organic unit. When storing these magnets, plastic bags can be used to sort each magnet by identity for easy finding. Finally, it is also recommended that a boundary be put on the magnetic board for students with BVI. Without knowing when the board ends, the student could be looking for a letter that is too far right or left to reach.
Possible Limitations:

One limitation when using magnets is the initial prep work that is needed to be able to use these magnets. In addition, a question sheet or audio guide would be needed to provide students with questions to answer using their magnet boards. The biggest limitation is that students cannot submit or save their work for each problem, making it challenging for the teacher to formatively assess what concepts are sticking and what concepts need to be retaught.

Figure 6. The Lewis dot structure of CH₄ is shown using magnets with puffy paint letters and dots. The same molecule is then shown in the skeletal structure, where two dots are replaced with a bond.
Metric System Activity

Universal STEM

Purpose:

The Metric System Activity allows students to explore length scales within the metric system. Different lengths correspond to different metric units and are presented as different textures on a wooden board. This activity is a successful method to teach the metric system to students with BVI and explain orders of magnitude within the metric system.

Sense Used: Touch

Supplies Needed:

- 1m wooden board
- 1dm rubber disc; 1cm rubber discs
- Sandpaper (P20 150, 1000, 2000)

Rationale and examples:

The metric system is deeply embedded into the curriculum of math-based STEM courses. For students with BVI, it can be a challenge to visualize the length scales within the system. When particle measurements become too small to see with the naked eye, it can be a challenge for all students to visualize and comprehend the orders of magnitude. Presenting students with an activity where they can explore various lengths starting at 1 meter and dropping down to 1 micrometer, can be a successful introduction to the metric system. Stender et al. (2016) reports on an activity where length scales are paired with a tactile representation. The Metric System Activity includes a 1m wooden board with tiles of different metric units, including 1dm, 1cm, 1mm, 100μm, 10μm, 1μm. As seen in Figure 7. The decimeter and centimeter are represented with rubber discs, while the millimeter down to the micrometer are represented with sandpaper. To complete this activity, a professor or adult would need to explain how each unit increases or decreases by a factor of 10. The exploration and explanation would take about 5-10 minutes. Braille labeling would be included under each tile to accommodate students with BVI.
For a student with full blindness, such as Student A, this activity would allow them to explore and feel the difference in sized particles within the metric system. Student A can move back and forth between tiles to get a better feel for the different units, especially between the sandpaper. For a student who has a visual impairment, such as Student B, they would be able to rely on multiple senses when making their observations and inferences about the different tiles. The extremely small particles on the sandpaper would not limit Student B from participating fully in learning the metric system. For a student with full sight, such as Student C, including these tactile representations creates a multisensory approach to learning the orders of magnitude of the metric system and can increase comprehension.

**Recommendations:**

This activity could be updated to include a wider variety of measurements used in STEM. The board has the ability to be customized in accordance with the classroom it will be used in, if the board is being made from scratch. It is recommended that when using the activity, there is a professor or another individual present to explain the factors of 10 and how they contribute to the metric system. This activity would be best used as an introduction to measurement lesson or within an introduction unit.
Possible Limitations:

Without some reading or labeling in regard to the factors of 10, this activity is not completely independent. A professor or demonstrator is needed to explain the factors of 10 between each example on the wooden board to provide the student with a fuller understanding of the metric system and how to convert between lengths.

Figure 8. The participant and demonstrator are shown on the left and right, respectively. The participant explores the length scales, while the demonstrator explains the changes in magnitudes of 10.
Optical Lenses

Physics

Purpose:

The Optical Lenses activity introduces a way to learn and explore lenses in a tactile way. Rope is used to represent the rays of light and the reflection of light through a shaped material, used to represent a lens. Different shapes, such as convergent and divergent, were explored. This activity was specifically designed to increase inclusion and full participation from students with BVI in a STEM classroom.

Sense Used: Touch

Supplies Needed:

- 3 corkboards
- Plastic shapes (convex, concave, astigmatic semi-convex)
- Thumb tacks
- Thick string/rope

Rationale and examples:

The refraction of light through a lens is a highly visual concept and for a student with BVI, an alternative method is needed to learn about refraction through a lens. Kumar et al. (2018) presents a tactile activity that uses rope as the movement of light and a shaped plastic as the various lenses. Students with BVI can have a special liking to the Optical Lenses activity because of the connection to the human eye. For this activity, three corkboards are set up, each with their own “lens” or shaped plastic piece. Typically, one is a convex lens, one is a concave lens, and one is an astigmatic semi-convex lens. Rope is then attached to the corkboard using thumb tacks and begins to travel in parallel lines through the lens. The rope will then change direction depending on the type of lens it travels through. For a convex lens, the rope will travel to a single central focal point. For a concave lens, the rope will travel away from the central focal point. For an astigmatic semi-convex lens, the rope will travel to a central point, but not all hit the same exact spot. These set ups can be seen below in Figure 9. A professor or
demonstrator will be needed to explain the activity to students and be there to guide any misconceptions during exploration (Kumar et al., 2018).

For Student A, who is blind, having a tactile representation of a visual concept will be essential for his or her ability to learn about lenses and light refracted through them. Having this secondary method will help promote inclusion within the classroom. For a student who has a visual impairment, Student B, this activity could prove to have a special connection because it relates to the human eye and why an individual may have a visual impairment. The activity also relies on a secondary sense, assisting Student B understand the concept being presented. For a fully sighted student, Student C, this multisensory approach to learning can increase comprehension. Light can be challenging to track without a more tangible example.

**Figure 9.** Three corkboards are shown, each with various lenses. Thick rope is tacked to the board and directed in a way to represent the reflection of light through the lens. A demonstrator is also shown explaining the activity to a participant.
**Recommendations:**

It is recommended that a professor or demonstrator is present to explain the activity and to guide exploration if misconceptions arise. It can be advantageous to use an astigmatic semi-convex lens as one of the examples. Students with BVI can relate to this because of the human eye, and all students know someone in their life that wears glasses. All of the lenses provided in the activity can be linked to a real-world example, such as a magnifying glass for convex, a flashlight for concave, or a human eye for convex or astigmatic semi-convex.

**Possible Limitations:**

By creating this alternative method to learning about light, you use the actual use of light itself and its ability to be refracted. Supplemental examples and demonstrations can be added to reconnect to the original concept. Another limitation is that this activity isn’t meant for a full class demonstration. A small group or station learning method would be best fit. With multiple groups or stations, this could increase the number of materials needed or the time-consuming nature of the activity.
Project 3D Image Arrays to Graphically Implement New Education (IMAGINE)

Universal STEM

Purpose:

Project 3D IMAGINE, or Image Arrays to Graphically Implement New Education, is a new study where students use a tactile learning technique, through a raised 3D printed image and Braille labeling. As 3D printers become more common in schools, this technique becomes more readily available for both STEM classrooms. Independently interpreting an image can help draw interest and enthusiasm about the given STEM topic for students with BVI.

Sense Used: Touch

Supplies Needed:

- 3D printer
- Computer/ Laptop

Rationale and examples:

As 3D printers become more common in schools, the availability of this alternative learning style increases. Students with BVI now have the opportunity to interpret an image without relying on another individual’s perception of the image. Project 3D IMAGINE researched various materials but suggest that using a high-density plastic would provide the best results. Complex images can be simplified for easier printing and for easier interpretation by an individual. This technique can easily be implemented into STEM classrooms or used across other disciplines outside of STEM. Including Braille labeling is essential to increase the independence of the user (Hasper et al., 2015).
Many available software will easily convert your 2D image into a format compatible for 3D printing. However, if this software is not available, the general process for converting an image starts by creating the image as a PNG file. The image must then be changed to high contrast outline. The white space will be blank, while the black space will be lifted when printed. This contrasted PNG image will then need to be converted to a SVG file, then to a STL file. Resizing can now occur and backing can be added. Words can also be included, or in this case Braille labeling would be added.

**Recommendations:**

This 3D printing technique can be used for independent classwork, highly visual curriculum topics, or take-home assignments. To obtain the best printed image, it is recommended to use a high-density plastic (HDP) because it is more easily trimmed and has fewer limitations. This is the material currently used to create public signs for restrooms, room signs, ATMs, and others. It is also recommended that for more complex images, a gradual introduction of details be implemented for the student to feel. For example, start with a general outline of the image being printed, then in a second print out add major details, and in a final print out add in smaller details completing the image.
Possible Limitations:

3D printing complex images can be a challenge when attempting to interpret them. Simple images are recommended when possible, or a gradual increase in details can be done if this is not possible. User experience and practice interpreting tactile images are often needed for effective results. Tactile images are not the ideal quick fix solution for students with BVI. This technique also does not achieve full independence, as students often need context about the image they are touching, but it is a support that moves in the right direction.

Figure 11. Shows how a teacher might alter the image of a chimpanzee to simplify the image for 3D printing. (A) shows the image that might be shown during class to all students. (B) shows the simplified version of the image. (C) shows how the contrasted and 3D printed image would turn out.
Puzzle Piece Formula Writing
Chemistry: Bonding & Formula Writing

Purpose:

These 3D printed chemistry puzzle pieces provide as way for students with BVI to learn, create, and manipulate ions, compounds, and chemical reactions. Pieces include chemical elements, numbers, arrows, symbols, and more. Each piece includes the conventional alphanumeric letters and Braille labeling to enable collaboration between sighted and non-sighted students. The goal of this adaptation is to create an inclusive learning environment where everyone receives the support they need.

Sense Used: Touch

Supplies Needed:

- 3D printer
- 3D printing model .stl download
  
  (https://pubs.acs.org/doi/10.1021/acs.jchemed.9b00255)

Rationale and examples:

The basic skill of writing and balancing chemical equations sets a foundation for more complex and higher-level skills in the future. When writing chemical equations, students need to be aware of basic conventions, be familiar with charges associated with different chemical species, and understand the valence electron ability to form a bond. Typically, in a high school or undergraduate chemistry class this information is taught in a written or visual fashion. Singhal and Balaji (2020) present a tactile learning method for students with BVI by using 3D printed chemistry puzzle pieces. Large pieces include two puzzle piece attachment sites and consist of elements, coefficients, equations arrows, and the addition symbol. Both brackets and parentheses are included for chemical reactions as well. Small pieces consist of one attachment site, therefore can be placed as a subscript or a superscript. Numbers and plus and minus symbols are included to create ions or subscripts. Figure 12 shows a sketch of what each puzzle piece would look like and the possible pieces to print. Each piece has the ability to interlock with another in a linear fashion, allowing for numerous different connections, as seen in Figure
13, Figure 14, and Figure 15. The ion, compound, or reaction that is being taught can easily be created by the teacher or the student. The creation can then be disassembled and used again for the next teachable moment. The RasMol’s CPK color scheme was adopted for this adaptation. In addition, both the conventional alphanumeric letters and Braille labeling are on each puzzle piece in order to encourage students of all abilities to work side by side in their chemistry classroom (Singhal & Balaji, 2020).

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<th>~ Weight, g</th>
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<td></td>
</tr>
<tr>
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<td>Blue</td>
<td>3</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Element</td>
<td>P (Phosphorous)</td>
<td>Orange</td>
<td>2</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Element</td>
<td>Fe (Iron)</td>
<td>Orange</td>
<td>3</td>
<td>16</td>
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<td>1</td>
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**Figure 12.** Possible puzzle piece cards are shown, along with their color, weight, average print time, and a sketch of the puzzle piece. Time to print and weight are dependent of the scale used.
Figure 13. A positively and negatively charged ion created using the puzzle pieces. (a) Fe$^{3+}$ (b) NO$_3^-$

Figure 14. Compounds can be written using ions or polyatomic ions. (a) Na$_3$PO$_4$ , (b) NaNO$_3$ , (c) Fe(NO$_3$)$_3$ , (d) FePO$_4$
For Student A, who is blind, these puzzle pieces provide a tactile method to learning a topic that is typically learned with a visual aid. Student A can move and interlock the pieces while working through problems and take advantage of the Braille labeling. Being able to work side by side with classmates using the same materials can help this student feel included and not singled out for needed additional support. For Student B, who has a visual impairment, the color differences can be a beneficial aid when working through problems with these tactile puzzle pieces. For a student who has full sight, such as Student C, these puzzle pieces provide a fun, engaging way to create about chemical ions, formulas, and reactions. The 3D printed puzzle pieces promote a growth mindset for all students, encouraging students to make changes as they go in order to work through complex or challenging problems.

**Recommendations:**

It is recommended that students are taught how to use and interlock the puzzle pieces before use. A short explanation about the placement of larger pieces versus the smaller pieces can cause less confusion when the pieces are manipulated. It is also recommended that when possible, the 3D pieces are printed in differing colors to help students with BVI differentiate between types of elements.

**Possible Limitations:**

One limitation about this adaptation is that a ACS pubs or Journal of Chemical Education subscription is required in order to access the .stl file for the 3D printing plans. However, once it is obtained once, it is possible to reuse the same information to print more or share it with a colleague. This tactile method also prevents students from saving or submitting their work for review. Perhaps pictures could be used in the future, so both the professor and the student receive feedback.
Figure 15. Chemical equations can be presented in a linear fashion by interlocking needed puzzle pieces.

(a) $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$, (b) $\text{C} + 2\text{H}_2 \rightarrow \text{CH}_4$, (c) $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$
The Sound and Feel of Data

Universal STEM

Purpose:

The Sound and Feel of Data activity presents graphically shown data in a tactile and auditory manner, increasing the accessibility for students with BVI in a STEM classroom. General trends, such as no change, linear, and parabolic, are presented to participants during this activity in a tactile manner using pipe cleaners and coins. In addition, a demonstrator will play musical notes, increasing in pitch as the participants moves up the y-axis. This introduction to graph trends can assist a student with BVI in a lecture or laboratory when this data trend is discussed.

Sense Used: Hearing & Touch

Supplies Needed:

- Pipe cleaners
- Coins
- Mobile phone sound app

Rationale and examples:

Graphical data is used constantly in the STEM workforce and is important to be understood throughout STEM courses in school. For students with BVI, graphical data can be felt and heard through the Sound and Feel of Data activity. For this activity, pipe cleaners will be set up as the x- and y-axis, while coins will represent data points, creating a general trendline. Students will be able to touch the coins and feel the shape they make along the graph. A professor or demonstrator will explain to the student the shape of the graph and an example it might represent. For example, a horizontal line of data points might represent how much a bottle of water costs each day at school; it does not change. This horizontal trendline should be the first introduced to the students. The second trendline should be a direct, linear trendline, increasing in y-value as the x-value increases. The final trend should be a parabolic graph. Because this graph will be the most complex, the real-world application of tracking a ball after it has been thrown can be used. After allowing the students to explore these graphs in a tactile
manner, a secondary approach can be introduced. As the student moves along the data points, a professor or demonstrator will use a sound app, increasing or decreasing pitch depending on the y-value. This adds a multisensory approach to learning the general trends of graphical data (Kumar et al., 2018).

For a student who is blind or has a visual impairment, such as Student A or B, this activity could be used to learn about general trends, slopes, or peaks. This learning could then be brought into the classroom and Student A/B would have a better visual of the data when a certain graphical trend is talked about in a lecture. Both the tactile and auditory representations could be assistance for future learning. For a student who has full sight, Student C, he or she most likely wouldn’t benefit from the tactile representation, as the original visual would be just as effective. However, the auditory representation paired with graph visual could be an effective multisensory approach to learning about graphical data.

Figure 16. (A) A tactile version of a parabolic graph is represented using pipe cleaners as the axes and pennies as the data points. (B) Participants are shown observing a tactile graph showing a horizontal line with a professor explaining what is occurring in the graph.
Recommendations:

First completing the tactile portion of the activity, followed by the auditory portion of the activity is recommended for best comprehension. It is useful for the students to understand how the graph might be shaped, before having sound added to their sensory inputs. It is also recommended that the activity starts by introducing a horizontal data line, showing know change on the y-axis, then moving to a linear trend, followed by a parabolic trend. This activity would be best used in a small group learning environment or during stations in a classroom.

Possible Limitations:

This activity requires a set amount of prep time and coins can easily fall out of place when moving the page or when touched by the participant. A professor or adult would need to be present to ensure that the coins did not move throughout the activity and explain the type of graph that is currently being observed. These additional personnel may not be available in all classrooms.
Adaptations Using Auditory Representations
Hearing the Electromagnetic Spectrum
Chemistry: Atomics and Physics

Purpose:

Hearing the Electromagnetic Spectrum is an auditory approach to learning a highly visual concept. This adaptation was specifically designed for students with BVI in a chemistry or physics classroom. The visual waves created by the electromagnetic spectrum are paired with auditory sound waves; both are shown and played simultaneously, creating a more inclusive classroom for all students.

Sense Used: Hearing

Supplies Needed:

- Function Generator
- Oscilloscope
- Speakers (headphones optional)

Rationale and examples:

The electromagnetic spectrum is completely nonvisible, except for the small portion seen as visible light. To help all students to learn about these invisible waves, The Electromagnetic Spectrum module uses an auditory acoustic frequency change to indicate a change in wavelength. In order to operate this module a function generator needs to be connected to an oscilloscope and speakers, which will project visible waves and audio waves, respectively. For the auditory signals, the acoustic frequency can be adjusted on the functional generator; there is a broad range available. Stender et al. (2016) choose to use the range of 1.5-10 kHz to coincide with human hearing. The longest wavelengths on the spectrum are paired with the lowest frequencies. The highest wavelengths are paired with the highest frequencies.
Figure 17. The function generator is connected to the oscilloscope, which provides visual waves to represent the electromagnetic spectrum. The speaks are also connected, which produce an auditory signal to match the wavelength being projected.

For a student with blindness, Student A, he or she can hear the variations in wavelength based on the frequency being projected. Student A can observe the changes right alongside classmates. For Student B, who has a visual impairment, multiple senses can be relied on when making observations about the changes in wavelengths. For a student with full sight, Student C, this multisensory approach to learning can improve understanding and can increase collaboration among all students. This multisensory approach to the electromagnetic spectrum is a useful adaptation to create a more inclusive environment for all.

**Recommendations:**

It is recommended that headphones or an audio splitter for headphones be used in a multigroup environment. When many speakers are projecting different frequencies simultaneously throughout the room, it can be challenging to differentiate between which speaker is producing which frequency. It is also recommended that ideas about how this modification be implemented into a lesson or laboratory exercise be talked amongst many different teachers,
when possible. There are many applications for this multisensory approach to learning the electromagnetic spectrum.

**Possible Limitations:**

If this combination is used in a multigroup setting, the accumulation of noises can be distracting and make it difficult to hear the speaker. Having headphones or an audio splitter for headphones can assist with this distraction. Because this is a general modification, creativity is needed to determine how to fit this into a lesson or lab activity. However, its general nature allows many possibilities for how it might be used.

**Figure 18.** The Electromagnetic spectrum includes as large range of wavelengths. Visible light is only a small piece of the spectrum. The wavelengths shown above can correspond to what might be shown on the oscilloscope while the speaker generates the sound waves.
Music with REDOX
Chemistry: Electrochemistry

Purpose:

Adding a greeting card music generator to an electrochemical cell demonstration can help engage students while teaching them about the power produced by the cell. Substituting in music for a light bulb accommodates students with BVI in the classroom, allowing them to make independent observations. These three “homemade” batteries are a great addition to a high school electrochemistry unit.

Sense Used: Hearing

Supplies Needed:

- Greeting card music generator
- Standard electrochemical cell supplies (Zn/CU(II) suggested)
- Lemon
- Solar panel

Rationale and examples:

Teacher demonstrations are an effective resource to engage students in the material being presented. One of the most common demonstrations in a high school chemistry curriculum, is an electrochemical cell to show an oxidation reduction reaction is occurring, producing power. Most teachers used light bulbs or monotone buzzers to show students how electrons are running through the wire, producing electricity. Cady (2014) produced a twist on this common demo by substituting a greeting card music generator for the light bulb. This feature is not only engaging, but it can be accommodating for students with BVI in the classroom. All students have the ability to hear the music generator play at a regular speed, but slow down as the battery from the electrochemical cell beings to lose power. Cady (2014) reports on three variations of a “homemade” electrochemical cell demonstration, including a Zn/Cu (II) cell, a Zn/H+ lemon battery, and a solar panel. All three variations are described in the sections below.
The Zinc/Copper(II) Electrochemical Cell with Music Generator

Using a standard Zn/Cu (II) cell seen in Figure 19, instead of connecting the two metal strips to one another directly with the needle nose micro clip wires, the music generator will be placed between the two metal strips. As power and electrons flow through the wires and through the music generator, the programmed song will play. As the power output decreases, the song will slow down and have a lower volume.

The Lemon Battery with Music Generator

The Zn/H⁺ lemon battery has the same general setup as the Zn/Cu (II) cell, however, instead of the two cells and a salt bridge, both electrodes would be pushed into the lemon. The strips should be close, but not touching as seen in Figure 20. This is a form of green chemistry as there is no hazardous waste, unlike the previous Zn/Cu (II) cell.

The Solar Panel with Music Generator

For the solar panel, the general concept is the same, but the setup is slightly different which is shown in Figure 20. The panel itself contains an electrochemical cell that acts as the battery when photons from sunlight undergo redox reactions. The music generator is connected to the solar panel, where the rechargeable battery was located after it is removed. Sunlight from outside or a flashlight/lamp can be used to illuminate the solar panel. As the intensity of the light changes, the speed or volume of the music will change simultaneously.
For a student with blindness, Student A, these slight modifications can allow him or her to make observations about the changes occurring in the electrochemical cells independently. They do not need to rely on someone else’s interpretation of the experiment in progress. They can also participate in the demonstration in the same exact fashion as their peers, promoting inclusivity. For a student with a visual impairment, Student B, he or she can rely on their sense of hearing, rather than their sense of sight to make observations. There will be no question if this student can fully capture the experiment occurring, and he or she will have a strong sense of confidence in the observations being made. For a student with full sight, Student C, using a greeting card music generator is simply a fun, engaging twist that using a alternative learning style and uses their sense of hearing.
Figure 20. (A) A Lemon Battery is made from a Zn/H⁺ electrochemical reaction. Both the zinc and copper(II) electrodes are pushed into the lemon; they are close, but not touching. The music generator is connected to each electrode wire, completing the circuit. (B) The music generator is connected to a solar panel, completing the circuit. The redox reaction occurs within the solar panel.

**Recommendations:**

To best engage students in this teacher demonstration, it is recommended that a well-recognized tune is chosen for the greeting card music generator, such as the song “Happy Birthday.” A teachable moment can be created by having both the Zn/Cu(II) electrochemical cell and the Lemon Battery set up at the same time. Each cell utilizes the same type of electrodes: zinc and copper, however different REDOX reactions are occurring in each cell. The Lemon Battery is actually a Zn/H⁺ battery. Suggested supplies

**Possible Limitations:**

These homemade batteries would be tough for students to actively participate with without modifying it to be a laboratory experiment. These electrochemical cells would be best as a teacher demonstration.
Verbal Descriptions for Images

Universal STEM

Purpose:

Verbally describing images in an effective manner can assist students with BVI mentally picture what the image looks like in their head. Guidelines and recommendations are flexible based on the particular student and his/her capabilities and strengths.

Sense Used: Hearing

Rationale and examples:

How well a student responds to a verbal description of an image can depend on the way it is being described, the student’s prior knowledge, and his or her ability to mentally manipulate a verbal description of an image. No supplies are needed for this strategy. This strategy can be used by all students, but typically is used for a student with BVI when a tactile image cannot be provided. Because this strategy is so dependent on the student and the learning preferences, creativity with how it might be used is limitless. A general rule is to avoid directional terms such as, “this, that, here, there” (Miecznikowski, Guberman-Pfeffer, & Donaruma, 2015).

Recommendations:

It is recommended first and foremost to get to know your student! Each student differs in learning preferences, strengths, and weaknesses; each student is going to need variations of how you verbally describe an image to them. A general rule, however, is to start with the overall shape of the object being described. Corners and sides can be numbered and individually described if applicable. It is also recommended that the student draws the shape in the air as a comprehension check for the professor describing the shape.

Possible Limitations:

The student’s ability to mentally create an image based on verbal descriptions is going to be the biggest factor on how this adaptation works. Each student is going to have different needs and a professor will need to adjust based on that particular student. The age of the student or the student’s capabilities can end up being a limitation for this strategy.
Technologies for a STEM Laboratory
Accessibility Thermometer

Universal STEM

Purpose:

The accessibility thermometer is a digital thermometer that will inform the user of the temperature through a digital reading as well as through beeps and vibrations. This multisensory output allows all students, including those with blindness and visual impairments the ability to fully participate in a STEM laboratory.

Sense Used: Touch & Hearing

Supplies Needed:

- Accessibility Thermometer controller
- Temperature sensor

Rationale and examples:

Vitoriano et al. (2016) created a low-cost digital thermometer that can be accessible by individuals with BVI. A sensor is attached to the reading device via wires, while the section of the probe that gets submerged in the solution is enclosed in a glass tube. Due to the structure of the thermometer, the entire bottom piece of the sensor must be completely submerged to get an accurate reading. The device can measure temperatures from -15°C to 115°C, making this range very useful for high school and higher education laboratories. Two modes are included in this accessible thermometer. The first is a “set point” mode, where the device measures the temperatures within a chosen range. Once in this range, the device will simultaneously produce beeping and vibrations. The second is a “numeric indicator” mode, where the actual temperature of a solution is measured. The device will emit beeps and vibrations in a certain sequence, much like Morse code, to indicate the value of the temperature. Multiple tests for this accessible thermometer were done side by side with two other standard thermometers. The results showed a correlation of 0.97 or greater when compared to both thermometers.

This accessible thermometer is designed for students with visual impairments or other disabilities, however, can be used by all students. For example, Student A who is completely
blind, can hear and feel the vibrations and beeps in order to determine the temperature being conveyed on the digital screen. Another student who has a less severe visual impairment, Student B, can also benefit from the multisensory output from the device. Both students with BVI have the opportunity to actively participate in the laboratory process; they no longer need to rely on their partner to read the thermometer for them and they are no longer stuck simply recording data. Student C, a fully sighted individual, can also benefit from the accessibility thermometer. This multi-sensual learning approach promotes students to use other senses and use their preferred learning style. The necessary materials for the accessibility thermometer are shown below in Figure 21.

Figure 21. The accessibility temperature controller (left) and the temperature sensor (right).
**Recommendations:**

It is important that the accessibility thermometer is fully submerged into the medium being measured. This will allow for the most accurate reading. It is also recommended that students are able to practice using this new device, as counting the number of beeps and vibrations can be a challenge when first being used. For certain experiments, multiple thermometers may be necessary if multiple mediums are being used. Having more than one device would accommodate for the 10 minute window for the device to reach thermal equilibrium.

**Possible Limitations:**

This research was done with a small test group, limiting the validity of effectiveness; and a larger test group is called for. The temperature reading range of -15°C to 115°C may limit the use of the accessibility thermometer in some higher education or professional laboratories. In addition, having a long window for the device to reach thermal equilibrium when using multiple mediums can prevent instantaneous feedback when needed.
SciVoice Talking LabQuest

Universal STEM

Purpose:

The SciVoice Talking LabQuest is an assistive technology with a text-to-speech option that enables students with BVI to collect, store, and graph data independently. Various probes can be attached to this hand-held device, including a temperature probe, a pH sensor, a drop counter, a gas pressure sensor, a light sensor, and a colorimeter. Other Vernier probes can also be attached as needed.

Sense Used: Hearing

Supplies Needed:

- SciVoice Talking LabQuest device
- Appropriate Vernier probe

Rationale and examples:

The SciVoice Talking LabQuest is an assistive technology that converts written text to audio speech. The device itself has an on-board computer with a touch screen for the user (Supalo, Isaacson, & Lombardi, 2014). The various Vernier probes that can be attached to the SciVoice Talking LabQuest allows this technology to be fairly universal among STEM disciplines. The addition of another mode of sensory output further allows students with BVI to actively participate in STEM laboratories. A student who is fully blind, Student A, can easily benefit from the text-to-speech ability. He or she can now collect and graph data using the SciVoice Talking LabQuest. Student B who has visual impairment can use the additional sense to be more independent in the laboratory. A fully sighted and able student, Student C, can also benefit from this multisensory style of learning. The accessibility component to this device also helps create an inclusive classroom where students of all abilities can collaborate for laboratory experiments.
Kroes et al. (2016) provides modified laboratory procedures for three chemistry experiments. These three labs include a Pressure Syringe Lab, an Acid and Base Titration, and an Endo/Exothermic Reaction Lab.

The Pressure Syringe Lab demonstrates the inverse relationship between pressure and volume. For the experiment, the Vernier Gas Pressure Sensor connects to a 20mL syringe. The other end of the sensor is connected to the SciVoice Talking LabQuest. The LabQuest will collect the measurements as the plunger of the syringe is moved in and out of selected volume readings. The LabQuest will also create a graph with the datapoints. All data can be read aloud to the student upon request. An additional tactile modification can be made by adding notches on the syringe to allow students with BVI the ability to stop at the designated volumes for the experiment.

The Acid and Base Titration requires two separate sensors, therefore two separate SciVoice Talking LabQuests are also needed. The Vernier Drop Counter was used to convert the number of drops released into a volume, needed for titration calculations. Simultaneously, the Vernier pH sensor was placed in the reaction beaker to track the changes in pH values. The reaction progress and pH changes are spoken aloud to the student. In order to find the endpoint, the student would need to go back into the SciVoice Talking LabQuest and search within the data table, where the text-to-speech option can be used.
The *Endo/Exothermic Reaction Lab* uses the temperature probe. As two different powders are placed into two different solutions, the temperature changes are tracked and recorded within the SciVoice Talking LabQuest. After the data is collected and graphed by the device, students are able to determine if the reaction was endothermic or exothermic based on the shape of the created graph. During this experiment, different beakers were labeled with rubber bands, to increase the independence of the student with BVI.

**Recommendations:**

It is recommended that the classroom teacher completes the necessary research on the device and the appropriate probes that will be needed. Some Vernier probes are not compatible with the Talking LabQuest and are only compatible with the original LabQuest. Additional time to order a probe may be needed. It may also be helpful for another lab group member to identify the heading of a data column that the SciVoice Talking LabQuest is reporting on, as the column headings are not processed by the text-to-speech function of the device. Other recommendations for the given laboratory experiments are provided within their description.

**Possible Limitations:**

The voice spoken by the SciVoice Talking LabQuest can be challenging for students to understand, especially upon first use. Differentiating between similar sounding numbers such as “16” and “60” is a place where a student with BVI may need confirmation from a peer. In addition, the power button is flush with the face of the device, which can create a challenge for students to turn on the device independently.
Sonified Infrared Spectra (SIRS)

Chemistry: Organic

Purpose:

The sonified infrared spectra (SIRS) is a technology that converts a graphical representation of an IR spectra into nonspeech audio sounds, allowing students with BVI the ability to interpret the data for themselves. SIRS can be used to identify one or more functional group in an organic molecule’s IR spectra. This technology is typically used in undergraduate organic chemistry courses.

Sense Used: Hearing

Supplies Needed:

- IR spectra data (can be downloaded from NIST database)
- JDXview v0.2 program
- CSV to MIDI converter

Rationale and examples:

The SIRS correlates the frequency of a musical instrument with the intensity of the absorption bands on the IR spectra. In addition, time markers at 3000, 2500, 2000, 1500, 1000 cm\(^{-1}\), and the end are included to allow the user to identify the location of the bands more quickly. IR data can be downloaded from the National Institute of Standards and Technology (NIST) database, or it can be obtained in a laboratory. Although IR data can be presented in a tactical graph format or in tabular form, these styles can be far more difficult to analyze when compared to the SIRS method. SIRS provides a straightforward and inexpensive alternative to allow students with BVI the opportunity to analyze organic IR spectra and determine functional groups independently (Pereira et al., 2013).
Figure 23. (a.) The molecule butanoic acid being analyzed with its functional groups highlighted. These colors correspond to the colors in the IR spectra. (b.) The IR spectra from the molecule butanoic acid with the highlighted function groups and where they would lie within the spectra.

For a student with full blindness, Student A, he or she can use the SIRS as an alternative to tactile graphs and therefore use a difference bodily sense. The ability to analyze their own data is gained by having this resource, making the student more independent in the classroom or laboratory activity. Student B may not have full sight and would not be able to easily differentiate between the distinct peaks within a complex IR spectra. SIRS would provide clarity and allow this student to identify the functional group being presented. This technique could also be useful for sighted students, as multisensory learning can lead to a better academic retention and a greater learning curve. Student C, a fully sighted student, can gain a better understanding of the information from an IR spectra while looking at the graphical representation and simultaneously listening to the sonified data. This approach encourages a well-rounded education and the use of multiple senses to learn.
Recommendations:

In order to successfully use this technology, audio training is recommended in order for the student to be familiar with the process of identification. IR spectra are fairly complex, so introducing a new output to this technique calls for training prior to use. It is recommended that organic molecules with single functional groups are used to train students to better understand the changes in frequency and the time markers within the SIRS technology. SIRS may be best applied in an advanced high school chemistry course or in an undergraduate chemistry course.

Possible Limitations:

A possible limitation for the SIRS technology is a lack of proper training prior to using the audio output. Without understanding of what is being heard or how a graphical representation is being converted can create a severe lack of understanding. In addition, as the number of functional groups within a molecule increases, the more complex as SIRS would be; therefore the user would need to be more familiar with how it works and have ample practice with the technology.
Titration ColorCam (TCC)
Chemistry: Acids and Bases

Purpose:
Titration ColorCam converts the visual process of titration, including a color change, into both tactile and auditory representations. This support allows students with BVI to indicate when a titration is taking place and when an equivalence point is reached. Students no longer need to sit back and let their peers complete the neutralization reaction for them, students with BVI can be an active part of the experiment and the learning process.

Sense Used: Touch & Hearing

Supplies Needed:
- Android Device with a camera function (phone, tablet, etc.)

Rationale and examples:
According to Bandyopadhyay and Rathod (2017), the free of charge Android-based app, called Titration ColorCam (TCC), uses the camera of a smartphone to detect changes in the color components (hue, saturation, value) of a solution. The app then signals these changes via audio (beep sounds) and tactile (device vibration). As the student gets closer to the equivalence point, or end point, the number of beeps begins to increase, telling the student to slow down the addition rate of the titrant. Once the equivalence point is reached and the titration is completed, the device will produce a continuous sound and a prolonged vibration. The Titration ColorCam can be used with a wide variety of indicators to best support the needs of the experiment. The general process of how the TCC is run can be seen in Figure 24 below.
Figure 24. Screenshots from the Titration ColorCam being used for a titration. (a.) The initial stage before titrant is added. (b.) Titrant is being added, and the device begins to vibrate and beep. (c.) The equivalence point has been reached, indicated by more aggressive vibrations and more frequent beeps.

This application can be used by a student with blindness, Student A, who would use both the vibrations and the audio beeps from the device when the equivalence point is approaching and when it has been reached. Student A would most likely need to be the partner operating the device, not the partner operating the burette. Student A’s job would be to tell his or her partner when to slow or stop the addition of the titrant. By having the TCC, this student is still actively involved, while playing a major role in the experiment. Student B could be an individual with color blindness or another form of visual impairment. This student would also use the vibrations and beeps from the TCC to understand when the color is changing; a change that may not have been noticeable without the device. Student B potentially would have the option to be the partner operating the device or the partner operating the burette, depending on the situation. Having the TCC eliminates the limitation of changing color for students like Student B. Finally, Student C is a fully sighted individual with no visual impairments. Student C can still benefit from the multisensory feedback from the device about the experiment occurring. Having an additional two methods of indication can help all students more fully understand the concepts occurring during the titration process.
**Recommendations:**

Much like a typical high school titration lab, a lab group of 2 students would be needed. One student could be adding titrant, while the second student holds the device to feel for vibrations and track the neutralization reaction via the color change. Another simple recommendation is to monitor the light sources and background colors behind the glassware, as this could potentially throw off results from the TCC application. A white piece of paper can be placed behind the flask in order to better detect the color changes.

**Possible Limitations:**

Little research has been done to see how effective this application is when being used. The experimental error of a student with BVI compared to a fully sighted student is described as “comparable” but is not described any further. In the future, additional studies would need to occur in order to determine the accuracy and precision of the TCC application.
Technologies for a STEM Classroom
BrailleNote
Universal STEM

**Purpose:**

The BrailleNote is a computer device with a refreshable Braille display to assist individuals with BVI in their workplace or classroom. This device includes a Braille keyboard and newer versions include a touch screen with a Qwerty keyboard as well. Note-taking, calculations, and text to Braille translations can all be done with the BrailleNote. This technology would increase the independence of a student with BVI in a STEM classroom.

**Sense Used:** Hearing & Touch

**Supplies Needed:**

- BrailleNote device (or BrailleNote Touch model)

**Rationale and examples:**

The BrailleNote is a HumanWare made computer device that has internet access and is specifically made for individuals with BVI. It has a refreshable Braille display and has a Braille keyboard for user typing. Updated versions of this device, such as the BrailleNote Touch, also include a Qwerty keyboard on the touchscreen. The BrailleNote can be used to read word-processed documents, as a calculator, or as an electronic Braille typing device. Similar to a computer, multiple different pages can be open simultaneously and the user can flip back and forth as needed. Because the device has internet access, search features within a document or page are possible. A few advantages the BrailleNote offers includes note-taking, the ability to connect to a computer to display a PowerPoint in Braille, and translate between text and Braille (Harshman, Bretz, & Yezierski, 2013).
Figure 25. A student is using the BrailleNote Touch and Braille writing is shown at the bottom of the device on the braille display. The Braille keyboard at the top of the device can be used for typing or for navigating through pages and sites. They keyboard can be flipped over like a book page, uncovering the touch screen where a Qwerty keyboard.

For a student who is blind or has a severe visual impairment, this device has many advantages for lecture classes. The BrailleNote would allow the student to be included in a mainstream environment and be more independent during a STEM class lecture. He or she could take their own notes or use the device to work independently through practice problems. If the BrailleNote Touch was being used, the visual display could vastly increase collaboration between Student A or B and the professor or another classmate. A student with full sight, Student C, would not benefit from this device directly, but the touch screen display would allow Student C to collaborate with a student with BVI.

Recommendations:

The BrailleNote Touch model is recommended for a student learning environment. This tablet version still has all the capabilities listed for the BrailleNote, however also has a touch screen that would allow collaboration with another student or a professor. The BrailleNote Touch is
a Google certified device and is compatible with various Android Apps, that would prove useful in a STEM classroom.

**Possible Limitations:**

The complexity of the BrailleNote can take time for the user to become accustomed to, so this device may not be a short-term solution. However, it has the ability to be used across disciplines both in and outside of STEM classrooms. The BrailleNote also has a limited display, as it is only about 12 inches long, so it only projects a few words per line. This can cause the user to have to scroll through several lines before finding the desired information. Similar to a computer device, multiple different pages can be open at the same time but cannot be viewed at the same time. When reading a problem from one page and working on a separate page, everything cannot be seen simultaneously which can be problematic in some scenarios. Calculations involving a combination of numbers, symbols, and letters can be confused when read aloud by the BrailleNote.

![Figure 26. The BrailleNote touch is a Google certified tablet that has an Android platform allowing the use of Android Apps.](attachment:image.png)
**Brailler**

Universal STEM

**Purpose:**

The Brailler is a mechanical Braille typewriter designed for individuals with BVI. This typewriter can be used in all disciplines, but is especially useful for a lecture classroom. For a STEM classroom, the Brailler could be used for note-taking or mathematical exercises. This machine is another way to increase the independence of a student with BVI in STEM.

**Sense Used:** Touch

**Supplies Needed:**

- Brailler typewriter

**Rationale and examples:**

The Brailler is a nonelectric typewriter that has a Braille keyboard and is primarily used by individuals within the BVI community. Special paper is needed to properly create durable dots; a common paper used is the 11 x 11 ½ heavy paper ream. This Perkins product can be used in any discipline or in the workplace, but it can be especially useful for mathematical exercises in a STEM classroom. The Brailler allows a student to view both the problem and his or her work simultaneously, unlike other devices.

For a student who is blind or visually impaired, such as Student A or B, this device could be used for note-taking or other typing. A professor could create a reference sheet for a STEM classroom and provide it to this student for test taking or for practice work. Having a sheet like this would decrease the amount of time spent searching for a specific formula or needed information, therefore decreasing the frustration level of the student. The Brailler would not be useful for a student who has not used a Braille keyboard before, such as Student C who is fully sighted, as there is no Qwerty keyboard. The device itself does not have translation capabilities, so this device would not assist with collaboration between Student A and Student C (Harshman, Bretz, & Yezierski, 2013).
Figure 27. A Brailler typewriter includes a Braille keyboard and special paper is fed through the device to create durable dots.

Recommendations:

The Brailler is an excellent choice for mathematical exercises, as the student can have both the problem and his or her work in front of them simultaneously. The Brailler is recommended for these types of problem solving, compared to the BrailleNote, which is often used for similar situations. It is recommended that the professor provides a student with a reference sheet or equations sheet by with help from the Brailler. 11 x 11 ½ heavy paper ream is the ideal paper choice for Braille typing, as it produced durable, easy to read dots.

Possible Limitations:

The Brailler is fairly low technology based and can be considered old fashioned when compared to its competitor, the BrailleNote Touch. The Brailler has no search capabilities, does not connect to the internet, and cannot translate between text and Braille. This can limit the amount of collaboration between all students that is possible with this machine. The Brailler is best used for independent note-taking or for independent mathematical problem solving.
ChemDraw
Biochemistry & Chemistry: Organic

Purpose:
This PerkinElmer product enhances previous ChemDraw capabilities to be more accessible and inclusive, especially for individuals with BVI. Users can build or upload molecular structures as needed and can label the molecules with Braille labeling. This multisensory approach to organic chemistry and biochemistry breaks down the visual barrier for individuals with BVI and creates a more inclusive classroom.

Sense Used: Hearing

Supplies Needed:
- ChemDraw software

Rationale and examples:
ChemDraw version 13.0.0.3015 now allows users to label elements on molecules in Braille labeling. Within the software, molecules can be built from scratch or can be uploaded from the connected online organic chemical structures library. An individual with BVI would access this library via the spoken output of the text-to-speech function (Supalo & Kennedy, 2014).

For a student with full blindness, Student A, he or she may take advantage of the Braille labeling option when creating or when being given a molecule within ChemDraw. Student B, who is visually impaired, could potentially take advantage of the Braille labeling as well, depending on the need. Both Student B and Student C, a fully sighted individual, would more easily be able to collaborate with Student A, through the use of ChemDraw. Increased collaboration promotes inclusivity in the classroom and allows Student A to fully participate in a high school or higher level chemistry classroom.
**Figure 28.** On the left, a molecule created in ChemDraw is shown. On the right, that molecule is then given Braille labeling within the software. This image is a printout of the updated molecule using the Picture in a Flash technology.

**Recommendations:**

It is recommended that when using an available Braille font within ChemDraw that the font Braille29 is used. It can also be beneficial to pair this option with an external printing method, such as Picture in a Flash, 3D printing, or another Braille compatible method.

**Possible Limitations:**

In order to successful work the accommodations within ChemDraw, the user must be able to work a keyboard and learn the proper key combinations to open the needed options. Another limitation is the lack of tactile response from the ChemDraw software. Because the molecular structures are on a computer screen, the sense of touch cannot be included unless paired with an outside printing method.
Figure 29. The ChemDraw platform is shown and a few general directions are indicated using red arrows. Organic molecules undergoing a reaction with Braille labeling is shown in the workbox. Elements in molecules, reactants, and products are all given Braille labeling.
Chemical Literature extraction and Aloud-reading System (CLeArS)

Chemistry: Organic

Purpose:

The Chemical Literature extraction and Aloud-reading System (CLeArS) software separates written text from images of chemical compounds within a textbook or article page. The system will then read both the text aloud and identify the given chemical compound aloud. Students with BVI can now effectively read their highly visual based chemistry textbook with ease, while working independently. This software is the first of its kind and can be a highly useful tool for the chemistry classroom.

Sense Used: Hearing

Supplies Needed:

- CLeArS software
- Textbook page or journal article with text and molecular structures

Rationale and examples:

CLeArS differentiates between text and image on a textbook page or on a journal article page. The density of pixels in each area is processed to allow the software to read the text aloud to the user without confusing the areas where a chemical compound, or image, is located. An example of how pixel density is determined is seen Figure 30. This method of pixels per line is one of the two methods used for the CLeArS software. The research team tested this aspect of the software using both articles from published academic papers, including complicated structures, and pages from a high school textbook, including less complicated structures. The success rate of the academic papers was 89.2% and the success rate of the textbook was 96.1%.

The system also has the ability to name the given chemical compound located on the page. Based on the research done by Kamijo et. Al (2016), The system could accurately identify the academic papers with a 48.3% success rate and the textbook pages with a 56.9% success rate. Looking further into why the system was not able to correctly identify certain compounds, it
was found that there was a significant decrease in correct answers for molecules including Carbon (C) and Hydrogen (H). The team suggests that this is because C and H are often not included in the chemical structure, but rather replaced by corners of a connecting line, or left off completely. In this regard, the prototype will need to be improved before this aspect can be effectively utilized (Kamijo et al., 2016).

For Student A, who is fully blind, the text-to-speech function can help read the text on the page aloud, while omitting the molecular structures. CLeArS can also assist with identifying and naming structures of organic compounds. The highly visual nature of naming organic compounds can be assisted with the CLeArS technology and could be a potential substitute for a tactile representation of a molecule. For a student who is partially blind or visually impaired, Student B, the same functions can be used as an additional support. Naming the chemical structure can help an individual see the complex bonds or functional groups that may be included. Student C, who has no visual impairments, the CLeArS software can still benefit their learning. Having another sensory input by having the text read aloud can help engage the reader and assist with pronouncing complex organic chemistry vocabulary or names. The naming process can be a challenge for all students, so having this assistive technology can be a great addition for any classroom and all students.

**Recommendations:**

When needed for naming an organic molecule, it is recommended that the carbon (C) and hydrogen (H) letters are included in the molecular structure to allow the CLeArS system to better process the information on the page. High school textbook pages may be the better choice for this aspect of the software.
Figure 30. The histogram of density of pixels per line. The difference between sentence area and chemical structure area can be seen on the far right of the image.

Possible Limitations:

Because CLeArS is a prototype and the first of its kind, there are many possible limitations that may occur. The unknown of the software in itself is the limitation. Another limitation is the molecular structure naming capabilities. The about 50% success rate can cause confusion for users until this success rate is significantly higher. It may need to be paired with a tactile representation of the organic molecule as well.
Listening-to-Complexity (L2C) Modules
Chemistry: Gas Laws & Kinetics

Purpose:

Listening-to-Complexity (L2C) models are computer activities that produce an audio output to indicate the movement of gas particles under various conditions. Students with BVI can participate in making observations about gas laws and kinetics with the help of this technology.

Sense Used: Hearing

Supplies Needed:

- NetLogo software
- Speakers or headphones

Rationale and examples:

Science inquiry learning is often highly visual in nature, presenting a problem for students who are blind or have visual impairments (BVI). Attempting to learn about gas laws and the movement and collisions of atoms can be difficult without a visual aid. In response, Levy and Lahav (2012) used a multiagent programmable modeling environment in order to create Listening-to-Complexity (L2C) activities in order to more effectively teach gas laws to students who have BVI.

The L2C model was created under the NetLogo modeling environment and consisted of an agent-based computer model, a recorded voice guide, and the interviewer. Instructions, explanations, and questions are prerecorded in order to allow more independence of the user. The L2C model will give the users real-time feedback as molecules are moving around the space. This movement could include increasing or decreasing velocity, changing location, or interacting with other objects or molecules. Both collision with walls and collisions with other gas particles can be included for the model. Various sound patterns are associated with the different movements and interactions, allowing the L2C system to deal with the rapidly changing complex gas particles, while still providing feedback. Levy and Lahav (2012) note that the sonification process, or the presentation of information using nonspeech sound, is most
effective when there were three or less audio channels occurring at the same time and if there was a greater frequency separation between sound streams. These subtle changes will allow the users with BVI to better interpret the movement of the gas particles. A sample of how a L2C model might look can be seen in Figure 31 or found at the following site: https://www.youtube.com/watch?v=c0EdRKdjfgk

**Figure 31.** An example of how the L2C interface may look for gas particles in a container. Many options and variations for the model are shown on the left-hand side of the screen capture.
Models that are available include:

1. Inflating a bicycle tire
2. Experimenting with particles
3. Kinetic Molecular Theory
4. Introducing pressure
5. Changing pressure
6. Diffusion of particles
7. Atmospheric pressure and gravitational force

Figure 32. Screen examples from various L2C models are shown. (A) Experimenting with particles. (B) Changing pressure. (C) Diffusion of particles. (D) Atmospheric pressure and gravitational force.
For a student who is blind, such as Student A, the L2C models can be a beneficial resource to hear how particles collide or change velocity when different variables are altered. The auditory response from the movement of particles can help the student comprehend but micro and macroscopic phenomenon. For a student who has a visual impairment, such as Student B, the model can potentially be run more independently while still providing the audio feedback about the movement of particles. The L2C models are also useful for a student with full sight, such as Student C. He or she can operate the model and change variables during exploration while observing the effects they cause. Student C and Student A could be paired together in a small group learning module to complete the computer model; Student C would operate the model and explain the changes being made, while both students can observe the sounds that are produced.

**Recommendations:**

The L2C models have the possibility to be used as a laboratory activity or a classroom learning activity. It is recommended that if multiple groups are using the models at the same time, headphones be used so that sounds are not crossed between groups. It is also recommended that a significant frequency separation is used between sounds played by the model, as it can be challenging to differentiate between similar sounds simultaneously.

**Possible Limitations:**

The biggest limitation of this technology is that a professor or demonstrator needs to operate the model for a student with BVI. There is currently no text to speech options available for the NetLogo software. Another limitation is that when three or more frequencies are being played simultaneously, the user’s ability to differentiate between them decreases.
NavMol 3.0
Biochemistry & Chemistry: Organic

Purpose:
The NavMol 3.0 software uses a multisensory approach to promote inclusion of all students in a chemistry or biochemistry classroom. This assistive technology allows for molecular structures and corresponding reactions to be created and interpreted within the system. In addition, further information about each atom, neighboring atom, and bond can be obtained via atom mapping. The visual barrier for students with BVI in a STEM classroom can be removed with the help of NavMol 3.0.

Sense Used: Hearing

Supplies Needed:
- NavMol 3.0 software

Rationale and examples:
Binev et al. (2018) have built a software based on previous NavMol creations to enable the communication and the interpretation of molecular structures and reactions. The NavMol 3.0 software utilizes cheminformatics to automatically identify molecular structures and voice synthesizers to read information. This software is a free download as a JAR file and requires Java JRE version 1.5 or newer in order to run. Within the software, users can load premade molecules from files and then jump from atom to atom through bonds. Information is given about each atom, the neighboring atoms, and the connecting bonds. This process of atom mapping is audibly announced to the user upon request.

For metabolic reactions, the user can also jump from the reactant atom to the corresponding product atom, which allows the interpretation of the changes occurring from a structural standpoint. Students and other users are able to edit molecular structures within the software by engaging with a keyboard or by using the text-to-speech option. Standard reaction templates to build off are included, allowing the user to more easily create the desired reaction. If a fragment of the reactant is changed, the software will automatically change the corresponding
site on the product molecule. Fragment templates have also been created to make easier editing access for all students, but especially for students with BVI (Binev et al., 2018).

For Student A, who is fully blind, the multisensory aspect of NavMol 3.0 is essential. This assistive technology can allow the user to more easily create molecules with complex fragments in order to create reactions. Atom mapping is also an excellent way to identify and familiarize general trends and the movement of electrons in reactions. Student B, who has another form of BVI, will be able to easily differentiate between nearby atoms in a large, complex structure while gaining information simultaneously; the premade fragments can be a great tool. The multisensory technology can be beneficial for a full sighted student, Student C, as well. NavMol 3.0 is an impactful learning tool for a STEM classroom.

Figure 33. A reaction of a ring molecule (M001) is shown in the top half of the image. The text box within the upper half of the image shows the user adding a premade fragment of Benzene. The result is shown in the bottom half of the image. The reaction automatically updates itself, showing the new product. Black solid lines connect each reactant atom to the corresponding product atom, giving further information about the reaction process.
**Recommendations:**

Being familiar with molecule and fragment names can be extremely helpful when working the NavMol 3.0 software. The premade fragments are listed by their names, so being familiar with functional groups and common structures, such as benzene, can decrease the time spend building a molecule or reaction. If the user wishes to import a molecule from files in standard chemistry format, small changes can always be made afterwards. The NavMol 3.0 technology can also be used as a complimentary teaching tool when looking at reactions and the movement of electrons. Students can explore how reactions change based on the reactant and the functional groups attached to them. NavMol 3.0 can also be used in the lecture or research portion of an organic chemistry or biochemistry laboratory to study the reactions being performed.

**Possible Limitations:**

A possible limitation for the NavMol 3.0 technology is that it fairly complex and requires prior knowledge about molecules, structures, naming. A newer student to biochemistry reactions or chemical structures may not benefit from this software as greatly. It many also be challenging for an individual with BVI to quickly visualize larger molecules, products, or fragments to see trends and types of reactions occurring. More time would be needed to completely interpret the reaction being done.
Purpose:

This Picture in a Flash (PIAF) Embosser is a classroom resource that produces tactile images from drawings, photocopies, or printouts from an inkjet printer. The PIAF capillary paper allows the ink of a 2D image to be raised, assisting an individual with BVI to understand and gain information. Both inclusivity and collaboration will increase during a STEM lesson or activity by using the PIAF Embosser.

Sense Used: Touch

Supplies Needed:

- PIAF Embosser machine
- PIAF capillary paper
- Inkjet Printer

Rationale and examples:

The Picture in a Flash technology is a tactile embosser that is Braille compatible. PIAF raises ink drawn by hand, photocopied, or printed from an inkjet printer, creating a raised surface whenever the ink was located. PIAF capillary paper is a special capsule or swell paper that is needed in order to raise the ink with the machine. After printing the image onto the capillary paper, it should sit for 2-3 minutes prior to placing it face up in the PIAF embosser machine. Occasionally, the image will need to be put through the machine more than once to ensure all parts of the ink are fully raised. Adding a tactile aspect to images, allows students with BVI to fully participate in a STEM learning activity (Supalo & Kennedy, 2014).

For Student A, who is fully blind, PIAF embosser would provide a very similar learning style that he or she might be used to. It is very common for students with BVI to use tactile representations to learn visual concepts both in the classroom and in their everyday lives. The PIAF embosser allows the sense of touch to be used when learning and understanding the shape of and information given from a graphical image. An example of how a chemical structure
might be raised can be seen in Figure 34. Student B, who has a visual impairment, can rely on a secondary sense to increase understanding and engagement. In the case a student may be color blind, different raised patterns can be used to indicate different colors on a graph or image. The PIAF is also beneficial for students with full sight, such as Student C. Having a multisensory approach to learning visual concepts can greatly increase engagement and understanding. The student can use his or her preferred learning style, while relying on a secondary learning style as well.

**Figure 34.** On the left, a molecule created in ChemDraw is shown. On the right, that molecule is then given Braille labeling within the software. This image is a printout of the updated molecule using the Picture in a Flash technology.

**Recommendations:**

The PIAF is a great tool for graphical information and is often used in Science and Math classrooms. PIAF is a universal STEM tool, but can also be used in other disciplines to assist students with BVI. This technology pairs well with other software that can create Braille labeling in accordance with the National Library Service (NLS) Braille dot specifications. For example, ChemDraw is a molecule building software where students can build or upload molecules and add Braille labels. Once printed, the PIAF can raise the lines and dots, making a tactile molecule for a student with BVI in a chemistry or biochemistry course.
Possible Limitations:

The PIAF embosser is not ideal of printing 3D images, as it only raises ink from 2D images. The machine is a high front end expense, and the purchase of the capillary paper is needed in order to produce raised images. The capillary paper can be run through the PIAF embosser many times before it no longer works, slightly decreases the amount of paper one would need to purchase.

Figure 35. A PIAF embosser machine is shown while processing a printed paper with black and white ink. The ink is raised upon going through the embosser.
QR Coded Audio Version of the Periodic Table of Elements

Chemistry: The Periodic Table

Purpose:

The QR coded audio version of the Periodic Table of Elements (QR-APTE) for a chemistry classroom is specifically designed to assist students with BVI. A QR code is assigned to each element and upon scanning the QR code with a smartphone, the student will be redirected to a link of a podcast audio file for each individual element. This podcast will dive into the history and the applications of that specific element, promoting a fun, exciting learning method.

Sense Used: Hearing

Supplies Needed:

- Smart Device with QR code scanning capabilities
- Poster or Screen projection of QR-APTE

(https://pubs.acs.org/doi/abs/10.1021/ed200541e)

Rationale and examples:

The QR-APTE is a teaching resource for professors and students when learning about the Periodic Table of Elements. Each element is assigned a personalized QR code that is linked to a short podcast, loaded with information about that specific element. The history, the applications, and the general chemical information are included in the podcast. Generally, each podcast is 5-10 minutes long, creating a new way to learn about an element in a chemistry classroom. With smartphones becoming more common, students can use their own device to scan the code as needed and can even access this information in their own home; internet access is needed for use. Bonifácio (2012) provide the QR-APTE poster in the supplemental information section of their article. The link for the poster is provided above in the Supplies Needed section. Braille labels can be added for each element in order to make this resource more accessible for students with BVI.
For Student A, a student who is fully blind, he or she can use the Braille labeling to scan the QR code on the QR-APTE. When directed to the podcast, this student can follow along with a partner or with the class while listening to the information given. No text-to-speech software is needed because it is not a written document, so words would not be confused or mispronounced by the software. For a student who has a visual impairment, Student B, he or she can also be included in the standard class activity through the podcast audio. Again, no text-to-speech software is needed. For all other students, designated as Student C, the QR-APTE is another method to obtain information in a new way. This multisensory approach to the Periodic Table of Elements can promote collaboration amongst all students. Any student also has the ability to go back to this resource as needed.

Figure 36. (a) Shows an individual scanning the QR code from the QR-APTE with a smart device. (b) The device will redirect to a podcast, where information about the specific element will be provided audibly.
**Recommendations:**

To optimize the accessibility, adding Braille labeling to the QR-APTE poster or printout is recommended. Students with BVI will then be able to independently access the information for each element as needed. The QR-APTE is a great complimentary teaching tool and could be used to assign classwork or homework when researching important elements. Internet access will be needed at home if assigned as homework. It is recommended that another form of the periodic table is introduced to a student with BVI, as this resource would not be allowed in a testing scenario.

**Possible Limitations:**

One limitation of the QR-APTE is the surplus of information provided in each podcast audio file. Although this may seem like a benefit, it can also be a limitation for a student trying to find simple information quickly. After learning about the element with this resource, it may be more beneficial to have a periodic table with Braille labeling to find quick information, such as average atomic mass, needed throughout a chemistry course. A second limitation can be seen when attempting to scan a QR code. The smartphone device must be held a certain distance away in order to properly scan and finding this optimal distance may prove challenging for a student with BVI. To help with this limitation, many smartphones produce a beep sound when the code has been scanned. Additionally, there is no transcript presented to coincide with the podcast. For a student who benefits from a textual input paired with an audio input, this resource would not be able to provide the ideal learning style for said student.
Chapter 4: Reflection

Creating an inclusive environment for all students in a STEM classroom can be challenging because of the hands-on nature of many activities, concepts, and laboratory experiments. The above compilation of resources for students with BVI allows these students the opportunity to actively participate in their STEM classrooms. The overall goal to increase interest in STEM and the continuation to higher education, which can be assisted by creating an engaging and accessible environment for all individuals. Using a multisensory approach to learning helps reach all students and can increase comprehension and academic success.

My research originally started a few years prior as a part of a graduate assignment. I was researching technologies for a chemistry classroom that could help a student with BVI participate in an experiment. This was for my own benefit as it might be something I could use in my future chemistry classroom. The more I discovered, the more I realized how having these resources in one place could benefit other teachers and districts. Each resource can be separated based on the sense it uses, the cost of the materials, or the discipline it can be implemented into. It can be tedious and time consuming for a teacher to sort through numerous academic journals and sift through the details to find these pieces of information; time that most teachers do not have to spare. The goal of my graduate work expanded from focusing on the student and the opportunities that can be provided, to also supporting teachers and districts when needed. Finding technologies and adaptations became a passion because of the large impact these tools could make for the many stakeholders. I have found many activities with a multisensory approach assist all students, regardless of ability, and enrich their academic experience.
Overtime I would like to add more technologies and adaptations to this compilation as they are found or created and provide a larger grouping of specific resources for physics, biology, and earth science classrooms. Because of how my research began, many of my resources are for a chemistry classroom. If this grouping proves useful for teachers and districts, my goal would be to create an online database where technologies and adaptations can be filtered and searched based on the sense used, the cost, or the discipline recommended.


Singhal, I., & Balaji, B. S. (2020). Creating atom representations using open-source, stackable 3D printed interlocking pieces with tactile features to support chemical equation writing for sighted and visually impaired students. *Journal of Chemical Education, 97*(1), 118-124. doi: 10.1021/acs.jchemed.9b00255


Supalo, C. A. (2016). ConfChem conference on interactive visualizations for chemistry teaching and learning: Concerns regarding accessible interfaces for students who are blind or have low vision. *Journal of Chemical Education, 93*(6), 1156-1159. doi: 10.1021/acs.jchemed.5b00603


