proposing accessible line standards

for tactile drafting accessibility for blind and low-vision students

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Note: In this article, the authors use identity-first language (e.g., disabled person, blind person) rather than person-first language (person with a disability, person who is blind) to refer to blind and low-vision people as the community prefers the identity-first convention.

It is important to realize that blind and low-vision individuals hold jobs in the engineering and architecture fields and methods that help them communicate can have reaching impacts.

Introduction

Drafting, the process of creating a technical drawing, has been a staple of education and work—at all levels—for many years. Producing construction documents for houses, structures, tools, fixtures, and parts has largely included a drafting process as a means of communicating and locating desired features in the produced item. Specifically, drafting has been one of the major means of creating a "plan" to produce the majority of products in existence today. The process of drafting has changed significantly over time: from stone tablets to high-tech three-dimensional models and virtual walkthroughs. Advances in technology have largely given way to a transition away from hand-drawn drafting practices to computer-based practices (Madsen & Madsen, 2016; Lieu & Sorby, 2009). Engineering Design Graphic courses, in both hand-drawn, and computer-aided form have been taught for decades (ITEEA, 2007) but have had to evolve to keep up with technological innovations (Barr and Juricic, 1994; Jenison, 1997). Developments in CAD drafting programs, solid-modeling software, and CAD/CAM programs have drastically changed the drafting process and its subsequent instruction.

In conjunction with the shift away from hand-drafting to CAD, some efforts have studied differences in these approaches (Brandon & McClain-Kark, 2008; Ozkan & Yildirim, 2016); specifically, many of these efforts have resulted in arguments for an increased emphasis on the spatial skills of intuition, reasoning, and visualization, which are more effectively developed through hand-drafting approaches (McLaren, 2007). On that note, Seidler and Korte (2009) argued that the process of hand drafting requires more understanding of what is being drawn before beginning than CAD and Wilson & Parrott (2011) reported that, when surveyed, students preferred hand-drafting approaches over CAD if they had prior experience with hand sketching and drawing. While students have expressed interest in hand drafting and the associated benefits, CAD approaches include significant advantages in productivity and uniformity in drawings across the industry. As CAD approaches have largely replaced all hand-drafting approaches, they have also had a distinct influence on the overall design process and experience (Condor, 1999). For example, different solid-modeling software options have largely facilitated prototype design and testing in a virtual setting, resulting in a significantly expedited production process.

However, despite contrary opinions on the virtues of hand- and CAD-drafting techniques, one commonality remains: little has been done to facilitate access to drafting (either by hand or via CAD) for blind and low-vision individuals. This is unfortunate as technical advancements in this area could also feasibly facilitate access for this population. Further, an exploration of the usefulness and accessibility of hand- and computer-aided approaches to drafting for blind and low-vision students does not exist in the literature.

This article presents tactile drafting techniques developed in collaboration with blind educators and students that have the potential to increase BLV students' access to drafting and engineering graphic curriculum in K-12 and higher education. This work builds on previous work funded by the National Science Foundation (Goodridge et al., 2019; Ashby et al., 2018; Lopez et al., 2020; Goodridge et al., 2021a; Goodridge et al., 2021b) and it is the authors' hope that some of the practices included herein will allow BLV youth to further develop technological and engineering literacy in related technology and engineering graphics courses.

How Many Individuals Could This Approach Serve?

Within 55 countries, there are approximately 37 million individuals who are blind and 124 million who have low vision (Fostner & Resnikoff, 2005). The United States Individuals with Disabilities Education Improvement Act of 1990 (amended in 2004) requires full access to education for students with disabilities, including blind and low-vision students, but there is still a significant lack of accessible learning opportunities for these individuals in many STEM areas (Beck-Winchatz & Riccobono, 2008; Rule, Stefanich, Boody, & Peiffer, 2011). The authors see this as a significant lost opportunity and, using 2015-2016 figures investigated by the National Center for Education Statistics (NCES, 2019), which noted 18% of the total bachelor's degrees awarded in the United States in STEM areas, there are nearly 6,660,000 BLV individuals who may have STEM interests if provided the opportunity.

Expanding the Curriculum by Taking a Step Back

The drafting techniques (hand-drawn and computer-aided) taught in drafting classes are largely confined to visual conventions. Conventions that assume that both the drafter and the audience are sighted—an assumption that does not hold for all potential students. Hand drafting offers techniques that are more readily adaptable to methods that are accessible to BLV populations.

Blind and low-vision people create and read drawings (and other spatial representations such as charts and figures) tactually with their fingers, just as they read Braille. These tactile representations, called tactile graphics, utilize raised lines, textures, and Braille to render all of the information that sighted people perceive visually (see Goodridge et al., 2019). To draw tactually, recent work has enabled blind and low-vision people to draw by hand using a tactile drawing board as seen in Figure 1. These boards have a rubberized surface that causes the paper (or other drawing material) to pucker and form a raised line as the person draws using a pen or stylus.

Like sighted people, blind and low-vision people use computers to do a variety of daily tasks (e.g., search the internet, communicate, write code). Unfortunately, a great deal of technology is built on the faulty assumption that everyone is sighted and, consequently, render those interfaces inaccessible to blind and low-vision people. Inaccessible technologies abound in U.S. K-12 education, from websites and standardized tests to eBooks, thereby excluding

Figure 1. Tactile Drawing Board

Figure 2. Manual Tactile Drawing Tools

blind and other disabled students from critical learning (Shaheen & Lohnes Watulak, 2019). While CAD and solid modeling software remain inaccessible to BLV students, the development of manual tactile drawing tools provides an opportunity for hand-drafting techniques to be utilized as an accessible option for blind and low-vision students (an example of these tools, such as Braille calipers and a tactile ruler is shown in Figure 2). Similar efforts have been seen in industry when architects have tried to communicate designs with BLV executives during renovations (see Figure 3).

Considering the prevalence of drafting courses in middle and secondary education, and the fact that most BLV students attend public schools, it is probable that a K-12 technology and engineering teacher may have a handful of blind students over the course of their career. Fortunately, the recent development of tactile drawing methods could begin to bridge such a gap and create a medium through which BLV students can learn about engineering graphics (Goodridge et al., 2019) This work continues and as presented herein, new suggestions around tactile drawing lineweights and linetypes may be an effective way for communicating technical material through touch. In essence, the authors, suggest that technology and engineering teachers consider *including* in their pedagogy—an intentional step to more traditional and tactile hand-drafting methods to accommodate any BLV students and let those who will be professionals in this area become familiar with

Figure 3. Raised line floor plans (white) and tactile 3-D model of rooms

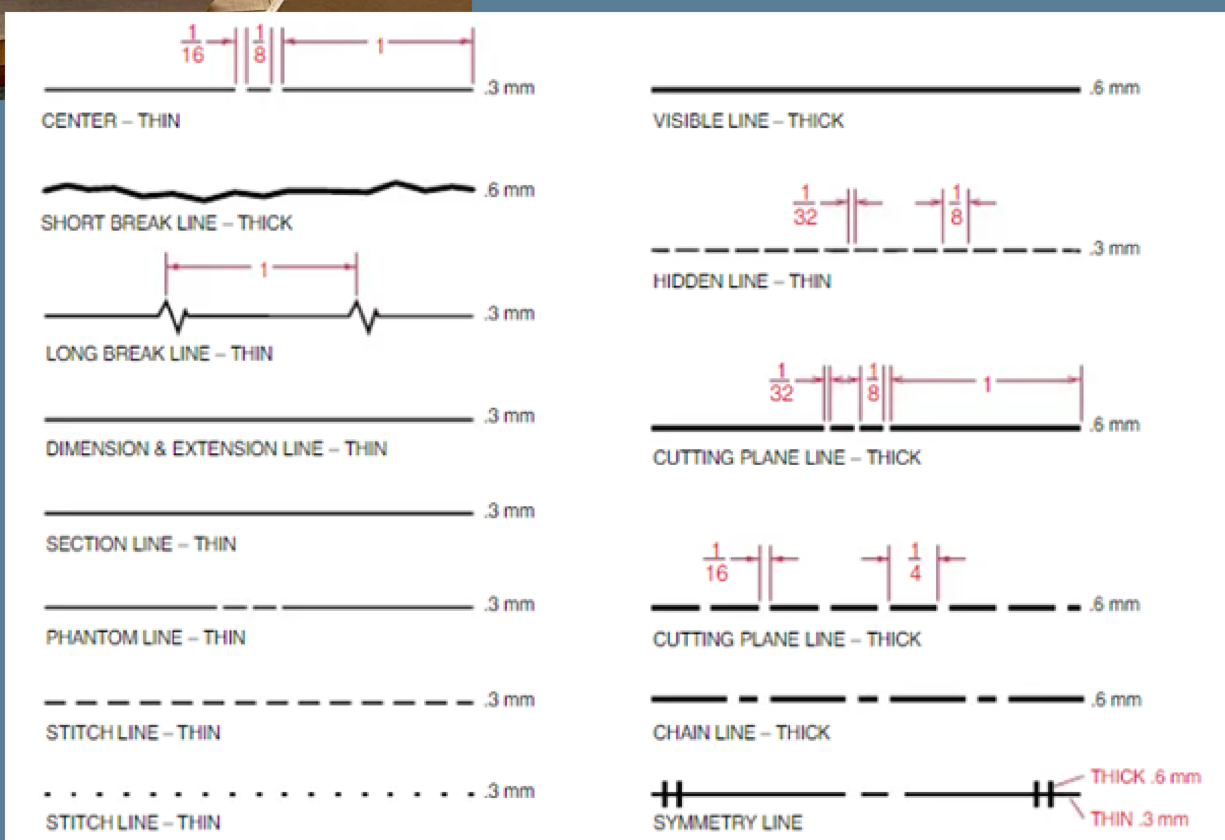

Figure 4. The Alphabet of Lines from Bertoline-Wiebe (2006).

the standards that the BLV community may use. The authors seek to provide suggestions and techniques that can help an educator accommodate a more diverse range of students in their drafting course. Historical drawing methods are more readily adaptable than more current CAD methods for tactile interpretation. The technology to implement such drawing techniques need not rely on needed computer accessibility but can leverage traditional means for a more immediate solution. This is not to say the authors are arguing against CAD or other technologically centered drafting practices as they are currently taught; rather, the authors are trying to provide tools and techniques that can lend themselves to being more accessible and adaptable and that may help diverse students develop technical literacy. These hand-drawing methods are envisioned to be implemented in instruction with a BLV student to allow them to develop skillsets and attributes that competency in engineering drawing can provide. Their use can open doors to a BLV student that typical CAD software may not allow to open. These techniques may also be of interest and benefit to sighted students *in addition to CAD and other techniques already in place*. The authors recognize that intentionally using *both* hand-drafting and CAD approaches in classrooms will not necessarily be detrimental should that route be chosen (e.g., while advances in technology have largely given way to a transition from hand-drawn drafting practices to computer-based practices (ITI, 2020), research into the CAD or hand-drafting approaches' effectiveness in teaching engineering graphics knowledge (e.g., hand-drafting and CAD) to sighted students is inconclusive); as an example, Brandon & McClain-Kark (2008) used 40 interior design students to investigate the differences in the two approaches (hand vs. CAD) in terms of overall design merit. Their results showed no significant advantage of either approach over the other. The authors also recognize the inherent advantages of CAD over hand-drafting in terms of the ability to rapidly reproduce lines faster, easier, and of higher quality; nevertheless, they acknowledge that there may be value in including both approaches—especially when a diverse student population in the class is present and communication with a diverse community may present itself to our future technologists and engineers. Unfortunately, BLV students are often prevented from engaging with CAD approaches due to inaccessible interfaces, which presents a loss of a significant opportunity to develop technical literacy.

Groundwork for a movement towards including *both* CAD- and tactile hand-drawing approaches, or implementing tactile hand-drawing approaches alone, begins with an investigation into, and an establishment of, linetypes and lineweights that are tactually interpretable through touch by BLV students. The authors present here some initial findings around the tactile interpretability of given linetypes and lineweights typically associated with engineering graphics coursework. The American National Standards Institute (ANSI) has typically dictated appropriate standards of lineweight and linetype to provide uniformity in drawing practices across the industry. Students introduced to drafting and engineering graphics must master these lineweights and linetypes to communicate efficiently amongst their peers and colleagues. A summary of these standards, found in Bertoline-Webb (2006) is seen in Figure 4.

Adapting these Lineweights and Linetypes

Tactile interpretation of linework on a tactile drawing presents an interesting dilemma as the affordances and limitations of visual perception differ from those of tactual perception. The linetypes and lineweights that are easily discernable visually are not always discernable tactually. With some initial investigation conducted at National Federation of the Blind programs and training centers, the authors present a discernable structure for BLV students to interpret via touch. Future research is needed to continue to validate and refine linetypes and lineweights that are tactually advantageous to BLV students.

The article is not suggesting a change in original ANSI line standards, but it is rather offering a separate set of standards to be used when rendering drawings in a tactile format for BLV students. This suggestion is made so that BLV students can better communicate engineering design and develop a sense of technical literacy. It is recognized that teachers will have to expand their knowledge base to include these standards, but their inclusion can enhance

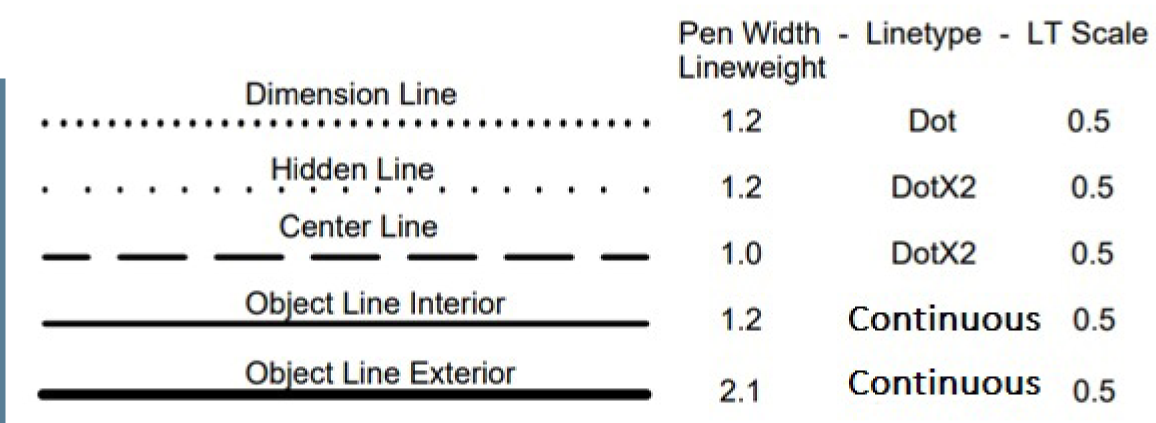

Figure 5. Initial Lineweight and Linetype recommendations for the BLV Drafting Student

accessibility for the BLV students that they may find in their courses. Figure 5 presents these newer tactile lineweight and linetype recommendations; in summary, two continuous linetype object lines are presented with a recommendation that 1.2 mm pen width be used for object lines for features interior to the object lines used to describe an object's perimeter. This allows tactile interpretation for transition between features seen within the view as opposed to those that establish the edges of the object as seen from that particular vantage point (front, top, R-side). The exterior object lines are suggested to have a lineweight of 2.1 mm. It has been observed that this allows the BLV student to discern that they are on the outside edge of a view rather than an edge internal to the view. This convention accounts for the methods by which tactile perception and nonvisual learning occurs—namely part-to-whole. The heavier external object line makes it easy for one to identify the boundary of an object tactually. Center lines are recommended to have a pen width of 1.0 mm and a DotX2 linetype in AutoCad. AutoCAD drawings may be produced and then developed into tactile graphics for BLV student interpretation. The steady size dashes available with this linetype are easier for the BLV student to track moving through an object to then locate a curve or circular feature. Hidden and center lines are recommended to maintain a 1.2 mm pen width and a Dot linetype for hidden lines and a DotX2 linetype for center lines. The reader will also note a significant increase in lineweight, which makes finding and tracing lines by touch much easier. The LT-scale found in the AutoCAD software is recommended to be set at 0.5 but is certainly adjustable by small amounts if needed.

The authors provide a simple multiview drawing using these BLV line standards (see Figure 6), which allows the reader to see the application of these five linetype and linescale recommendations as they present themselves in a typical engineering drawing. Technology and engineering teachers are encouraged to develop additional drawings for their instructional purposes using these initial BLV line standards. Additional work is currently in development investigating best practices concerning the line standards for other typical drafting lines not yet investigated with this work.

For the convenience of non-Braille readers, dimensions are provided in print. To make this drawing accessible, the lines must be raised and the dimensions provided in Braille. Raised lines can be made manually using tactile drawing tools or digitally using a Braille embosser or microcapsule paper and fuser. Both the manual and digital tools should be available to teachers through school districts' blind and low-vision services, usually part of the special education department.

Within Autodesk's AutoCAD software, setting the linetype, lineweight, and LT Scale standards through the layers interface allows linework to be visualized in model space and plotted via paper space. Some LT scale adjustment may be possible if needed, but it is recommended that it be informed by a BLV student or instructor regarding its tactile interpretation.

With a manual application on a tactile drafting board (Goodridge et al., 2019), spacing between dashes and dots should be close to 1/8 of an inch for center and hidden lines and 1/16 of an inch for dimension line dots (see Figure 5).

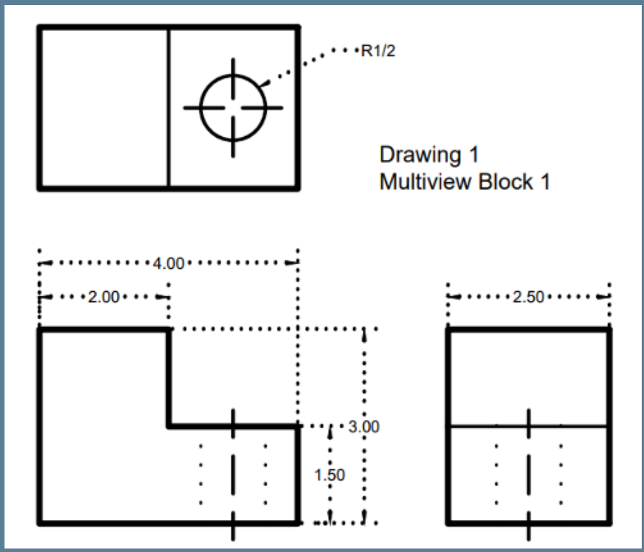

Figure 6. Simple author-created multiview drawing using recommended BLV line standards

Conclusion

The authors hope an opportunity exists for technology and engineering education instructors—at all levels of education—to consider their approaches to teaching drafting. Specifically, the authors advocate for the implementation of these new tactile drawing standards and techniques when a technology and engineering teacher finds themself needing to offer a more accessible curriculum to a BLV student. There is a hope that providing these methods can open a door to technical literacy for the BLV student that may not currently be present. Additionally, the authors also suggest teaching these techniques along with traditional ones in a class so that the class itself and the future work environment can be diversified and provide a means of communication between BLV and sighted peers. Finally, the authors present a lesson plan centered on this opportunity and encourage teachers to review it with a lens of consideration around how their own plans, practices, and approaches may be expanded and improved.

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Tactile Multi-view Drawing Development

Description: This activity will allow BLV students to experience multi-view drawings of simple introductory 3D solids similar to those taught in sighted drafting coursework. The BLV students will use an accessible drawing board, triangles, ballpoint pen, and braille caliper to create the drawings. They will either interpret a provided simple 3D solid or a snap cube-constructed model to then develop a front, right side, and top view of the object. Their drawing will be interpretable by another BLV peer through the sense of touch. Reversing the process to require a student to tactually interpret a multi-view drawing and then construct a snap cube model is also recommended. Students should also be taught how to scale drawings in this process.

Table 1. Multi-view Drawing Rubric

Item	Description	Pts Possible	Total
Front View	Present and tactually interpretable	12	
Top View	Present and tactually interpretable	12	
R.S. View	Present and tactually interpretable	11	
Views Align	Views should align correctly and be placed in appropriate locations on the paper	5	
Linework	Distinct and uniform tactile impressions from the ball point pen, fine and medium point. Dashes present on hidden, phantom, and center lines. Fine ballpoint pen used for these lines as well as object lines. Medium ball point pen used for object lines.	15	
Object lines	All required object lines present to describe features, made with fine tip ball point pen, Both continuous line types present (Figure 5).	5	
Hidden Lines	All required hidden line present to describe features, made with fine tip ball point pen, dotted linetype Hidden Linetype (Figure 5)	5	
Center Lines	All center lines present to locate features, made with fine tip ball point pen, short-dashed center line type (Figure 5)	5	
Border Lines	Border lines present to frame picture, made with medium tip ball point pen, heavier continuous Linetype (Figure 5)	5	
Title Block	Appropriate title block present with Braille information (detail is subject to instructor's discretion)	10	
Dimensions	All dimension linework desired by instructor is present, drawing with fine tip ball point pen, includes extension lines and dimension value in braille, dotted linetype Dimension Linetype (Figure 5)	10	
Notes	Any required notes present in braille format.	5	
TOTAL		100	

Table 2. BLV Multi-view Drawing Activity

Lesson Purpose:

In the lesson, BLV students are engaged in learning to develop tactile multi-view drawings requiring an understanding in 3rd angle projection, drawing layout, dimensioning, line weight and line type, and the mastery of tactile drawing instruments. Newer tactile lineweight and linetype standards are suggested. We believe this lesson provides an opportunity for BLV students to engage in a drawing process that can inform them of the ways that engineers, designers, and technologist communicate.

Lesson Duration: 1 week (Five 45-minute class periods)

Engineering Core Concepts and Sub-Concepts:

- **Engineering Design – Engineering Graphics**
  - Engineering Drawing
- **Measurement and Precision**
  - Measurement Instrumentation
  - Accurate Layout and Precision Measurement
- **Manufacturing** (Possible on Instructors Discretion)
  - Design for Manufacture

Global or Local Issue:

Accessibility in STEM education is a priority for all educators and their students. Additionally, as students need to become proficient in typical communication mediums used in TEE, this lesson attempts to address the issue of an instructor with a blind or low-vision (BLV) student who is desirous of having opportunities to learn the fundamentals of engineering graphics.

Connected STEM Standards:

Standards for Technological and Engineering Literacy

- *Standard 7:* Design in Technology and Engineering Education
- *Practice 3:* Making and Doing
- *Context 6:* The built environment

Mathematics

- Practice Standards
  - PS.4: Model with mathematics.
  - PS.5: Use appropriate tools strategically
  - PS.6: Attend to precision

Learning Objectives:

- I can create a multi-view drawing following 3rd angle projection techniques that will describe a simple 3D solid.
- I can demonstrate my knowledge of line type and line weight to begin to develop methods that will allow me to tactually communicate design to peers.

Enduring Understanding(s):

- Rules and principles of graphical communication are used to convey attributes of solid objects

Driving Question(s):

- Why is it important to communicate designs?
- What is the purpose of a multi-view drawing? What is the advantage of conveying information using a multi-view drawing over a pictorial drawing?
- Why are the views laid out on paper the way they are in a multi-view drawing?

Career Connections:

There is a wide variety of careers and professions associated with multi-view drawings and engineering graphics. Knowledge to be able to communicate designs capable of spanning a BLV and sighted medium can be important in opening venues to jobs in architecture, civil, mechanical, aerospace, biological, environmental engineering, drafting, and manufacturing. It is important to realize that blind and low-vision individuals hold jobs in the engineering and architecture fields and methods that help them communicate can have reaching impacts.

Required Student Prior Knowledge and Skills:

Integration of students' prior knowledge is critical in any successful lesson. In order to successfully build upon their knowledge, the following concepts are expected to be understood prior to beginning this lesson:

- Mathematics
  - Produce and analyze diagrams
  - Draw and identify lines and angles
  - Ability to convert between units of measurement
  - Ability to scale
- Engineering/Technology
  - Ability to choose correct tools for given task
  - Proper use of rulers and other measurement tools

Tools / Materials / Equipment

The following is a list of materials and equipment necessary for successful delivery of this lesson plan:

- Drafting table with rubber surface and parallel edge
- 30/60/90 notched triangle – notched by instructor
- 45/90 notched triangle – notched by instructor
- Fine and Medium tipped ball point pens – purchased at nearby Walmart
- 3D Drawing Objects – create by instructor
- Tactile Ortho Cube – created by instructor
- Snap Cubes – purchased on Amazon
- Braille Caliper – purchased from the National Braille Press

Daily Plan

(Times can be variable based on the prior knowledge and adaptive skills of the student)

Day 1: Familiarization with the Tools

1. Familiarize BLV students with using a Braille caliper to measure an object and let them measure some objects. (10 min)
2. Familiarize the BLV student with the tactile drawing board, parallel rule (edge), and triangles. (12 min)
3. Familiarize the BLV student with drawing a line so it indents upon the paper. (3 min)
4. Introduce the new suggested hidden, object, and centerline line types and have student practice them (10 min)
5. Familiarize the BLV student with some simple objects they will draw. Let them feel the objects and interpret them. (5 min)
6. Familiarize the BLV student with feeling the line they have drawn. (1 min)
7. Let the BLV student experiment drawing more lines and ask them where they need help (4min)

Day 2:

1. Ask the BLV student to draw two parallel lines. (2 min)
2. Ask the BLV student to draw a centerline, object line, and hidden line across the page 5 times for each. (10 min)
3. Ask the BLV student to draw a square (any size). (5 min)
4. Ask the student to draw a rectangle measuring 5 inches on its base and 3 inches on its height. (8 min)
5. Ask the BLV student to draw a 1-inch by 1-inch square inside the rectangle and at its center. (10 min)
6. Ask the BLV student to draw a 6-inch by 4-inch right triangle. (8 min)
7. Ask the BLV student to reflect on their work today and assess it. (2 min)

Day 3:

1. Introduce BLV students to the Tactile Ortho Cube made of plexiglass that surrounds some 3D solid mounted on the dowel in the middle (Goodridge et al., 2019). Use the Tactile Ortho Cube to let students feel how views of a certain feature of the object project to its surfaces. Pay particular attention to projecting features to the Top, R-Side, and Front of the cube. (15 min)
2. Unfold the cube on its hinge points to show the BLV student how the multi-view projections drawings are developed from a 3rd angle projection technique. (5 min)
3. Replace the Tactile Ortho Cube, place a new simple 3D solid inside, and have the student identify if that solid matches a previously prepared tactile graphic that the instructor created. (5 min)
4. Place a new 3D solid with a hole in it within the Tactile Ortho Cube and ask students to locate linework on appropriate views describing the hidden features of the holes. (5 min)
5. Hand out a multi-view drawing of an object along with the 3D model and ask BLV students to reproduce it. Coach them on using the instruments to do so. You will develop techniques with them that are highly individualized so think about how to help them locate the start of a line or its end and how to bring the instrument to that point to begin to develop a new line from it. (13 min)
6. Ask the BLV students to reflect on their work today and assess it. (2 min)

Day 4:

1. With the BLV students, develop one simple snap cube model (at least 4 pieces) and have them draw a multi-view drawing of the object. (10 min)
2. Discuss with the BLV student how to choose a most characteristic side to set as the front view. (2 min)
3. Ask the BLV student to make two more snap cube models requiring at least 6 pieces in their construction. (10 min)

4. Ask the BLV student to draw both of these models as a multi-view drawing. (21 min)
5. Ask the BLV student to reflect on their work today and assess it. (2 min)

Day 5:

1. Discuss the concept of scale with the BLV student. (3 min)
2. Hand the BLV student a simple model of an object and have them draw it at full scale. (10 min)
3. Have the BLV student repeat the multi-view drawing of the object at ½ scale. (10 min)
4. Hand the BLV student a 3d Object and have them use the braille caliper to measure features and tell you what they should draw their size as in a ½ scale drawing. (10 min)
5. Have the BLV student draw a multi-view drawing of a snap cube object that they can then build themselves. (10 min)
6. Ask the BLV student to reflect on their work today and assess it. (2 min)

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