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Spatial Language Used by Blind and Low-Vision High School Students During a Virtual Engineering Program (Research)

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Introduction

Spatial ability can be defined as the measure of a cognitive ability to generate, retain, retrieve, and transform well-structured visual images [1]. Various constructs of spatial ability exist including mental rotation, mental reconfiguration of complex shapes, and mental manipulation of spatial patterns [2]. This paper will refer to spatial ability as a quantification of performance on one construct of spatial thinking.

Research has demonstrated the value of strong spatial ability in areas such as geology, chemistry, biology, physics, engineering, mathematics, and surgery [3]. Of particular interest is the positive impact spatial ability has on undergraduate students studying science, technology, engineering, and mathematics (STEM) subjects [4]–[6]. Parallel to its positive influence on grades and test scores, spatial ability has been correlated with degree completion [7]. A study conducted in an engineering statics course revealed that students developed a considerable degree of spatial thinking throughout the course of the semester when compared with undergraduate students in other disciplines [8]. Similar to its relationship with undergraduate academic success, spatial ability is a profitable asset for professionals engaged in STEM careers [7], [9]. Research has found that spatial ability can be learned through targeted interventions, exposure to spatial language, and participation in spatial activities [10], [11]. Furthermore, once learned, spatial ability is malleable and can be maintained and developed over time [12]. This is particularly promising in the context of developing targeted interventions aimed at fostering spatial ability.

Of particular interest to the development of STEM curricula is how instructors' use of distinct spatial vocabulary can lead students to develop stronger spatial skills. Multiple studies have found that language itself does not heavily influence development of spatial ability [13]–[15]. However, other studies have found that while spatial language cannot independently determine spatial ability, teachers' use of spatial vocabulary can lead students to start thinking spatially which in turn maximizes spatial learning [14]. Capraro et al found that instructor use of precise spatial language optimized students' likelihood of creating accurate 3D drawings [16]. In another study exploring spatial literacy, many of the scores of participants with low marks in spatial communication were due to a lack of basic spatial vocabulary [17]. Training instructors in spatial vocabulary could have wide effects on how well students learn spatial thinking.

Despite the value spatial thinking adds to academic and professional development, very little research has been conducted to address spatial ability in blind and low vision (BLV) populations. Spatial ability has traditionally been tested, taught, and explained in a visual sense, however it is fundamentally a cognitive process in which vision is not a necessity [18]. There are many capable and talented BLV individuals engaged in STEM fields, but there can be a much larger potential for BLV participation in STEM fields if targeted interventions are able to encourage spatial ability development in these populations [19]. There is thus a need to develop more spatially oriented trainings that are accessible to BLV populations.

Although little work has been done to address spatial ability specifically in BLV populations, some research has been done to explore how members of this community interact with technical vocabulary. One such study suggests that many BLV students are less proficient in scientific vocabulary than their sighted peers and that their ability to use appropriate definitions affects their ability to work with scientific concepts [20]. Another study shows that BLV students often choose to use common vocabulary rather than scientific vocabulary in science courses [21]. Correctly used spatial language, however, has the potential to stimulate spatial thinking in students and the consistent use of spatial language by teachers, parents, and peers highlights the importance of spatial relations in everyday life which can spark a heightened sense of spatial awareness [22].

The purpose of this paper is to explore results from a qualitative study of how high school aged BLV youth used spatial language during a virtual engineering experience administered by the National Federation of the Blind (NFB). Findings from this study can provide recommendations to enhance language in curricula that better reflects BLV students' understanding of spatial content and may ultimately encourage more BLV students to pursue careers in STEM fields.

Methods

Data Collection Site and Participants

Data was collected during synchronous virtual Zoom sessions of the Engineering Quotient (EQ) program, an engineering experience administered by the NFB during the summer of 2021. Participants in the program included BLV teenagers from the United States in grades 9 through 12 during the 2020-2021 school year. The EQ program was designed to introduce BLV youth to STEM concepts, provide opportunities for interaction with fellow BLV peers, and encourage participants' spatial skill development and problem-solving ability. Prior to beginning the program, participants and their families were provided with an Institutional Review Board (IRB)-approved informed consent letter that allowed them to opt in or out of the research activities. Data was only captured from participants that signed and returned the informed consent letter. Out of the 35 total participants in the program, 13 provided consent or individual assent to participate in this research study.

Participants were mailed kits of instructional materials before the start of the program, which included tactile workbooks and supplies that supported the drawing and paper folding activities. Supplies for the activities included materials such as origami paper, drawing boards, and writing utensils. Also included in these kits was a vocabulary list of terminology that would be used throughout the paper folding activities in the program (presented in Table 4 in the Appendix). This list consisted of basic origami terminology such as "mountain fold," "valley fold," "raw edge," and "folded edge." This vocabulary list was included with the instructional materials in part because blind learners (as well as those who are sighted) learn and make meaning of vocabulary terms in written form, as well as when used and described verbally (as was the case during the program activities). The vocabulary list was chosen by a member of the project team who is blind and was based on her previous instructional experiences.

Each EQ program session included a community-building activity at the start of the session (e.g., discussing a current favorite movie or hobby), followed by one hour of guided paper folding origami instruction and activities, a 30 minute break, and another hour of a guided technical engineering drawing session. Program participants were split into two groups, with one group attending the paper folding session first and the second group attending the engineering drawing session first. After the 30 minute break, each group then completed the session that they had not yet participated in.

Paper folding/origami instructional sessions included activities such as learning how to fold a tessellation grid; folding index cards that would be assembled together to form a menger sponge; and folding a masu box using origami paper. Drawing sessions included activities such as learning how to represent three-dimensional objects (e.g., a cup) in two-dimensions in different perspectives (e.g., top, right, left) and learning how to represent different types of origami folds and features using different line types (e.g., a thick solid line for a raw edge, a dashed line for a folded edge).

Data Collection

The research team included five members: three researchers in engineering education and two researchers from a STEM research and evaluation center. The researchers observed at least one virtual EQ program session per week for 3 weeks. Each researcher followed an observation protocol in which they looked for words that students used that related to spatial ability or spatial thinking as they were engaging in the session activities. Researchers also captured the context in which the students were using the words and the possible meaning behind the words. During the 30 minute breaks in between the paper folding and drawing sessions, researchers solicited interviews from participants that consented in the research study. The researcher and participant moved into a separate Zoom breakout room to conduct the interviews, which lasted between three and ten minutes. The researcher asked for the participant's permission to record the virtual interview so it could be transcribed later for analysis. Participants were asked questions such as, "What words used in the activity did you find most difficult to understand?" and "What words used in the activity made sense to you and were easy to understand?"

Data Analysis

Field notes from the observations and transcripts from the interviews were analyzed using first and second cycle coding procedures [23] in MAXQDA, a qualitative data analysis software [24]. Two members of the research team independently analyzed the field notes and interview transcripts to identify codes relating to spatial language. The research team also used the origami vocabulary words that were in the students' kit of materials as a priori codes [23] to serve as a starting point for the first cycle of coding. After coding independently, the two research team members held meetings to discuss identified codes and resolve discrepancies. The two team members revised the code names, definitions, and application of the codes until an intercoder agreement of 90% was reached [23]. After this agreement was reached, the two team members began the second cycle of coding to identify themes that were characterized by the first cycle codes [23].

Results

Results from the first and second cycles of coding revealed five major themes: *Use of spatial language; Use of origami terminology; Preference of specific, succinct instruction; Use of different types of strategies;* and *Relationships among types of spatial language.* The following section will describe each of these major findings in detail with sample excerpts from the data.

Use of spatial language

Results demonstrated how the EQ program participants used spatial language and what types of language they used while completing the program activities. For example, participants used *directional words*, *geometric ideas*, and *reference points* when describing spatial features or explaining how to accomplish certain objectives.

Directional words included terms such as “right/left,” “up/down,” “horizontal/vertical,” “clockwise/counterclockwise,” and cardinal directions (i.e., north, south, east, and west). Table *1* provides descriptions of several of the *directional words* identified from the data and representative quotes from the participants as they used these words while completing the program activities.

Table 1

Types of directional words that were used by the EQ program participants along with sample quotes from these participants.

Directional words	**Sample participant quotes**
Right/left	“You can move it to the left”
Up/down	“Fold wings down”
Horizontal/vertical	“Fold [the paper] vertically”
Clockwise/counterclockwise	“Counterclockwise and clockwise for turning the paper”
Cardinal directions	“Fold paper along north-south axis”

Geometric ideas included language describing features in terms of configurations, shapes, or orientation. Examples of *geometric ideas* were “symmetry,” “proportion,” and shapes of lines (e.g., “zig zag line”). Specific words that were used that related to *geometric ideas* included “half,” “center,” “parallel/perpendicular,” and “intersect.” Table *2* provides several examples of *geometric ideas* and corresponding quotes from the participants as they engaged with the program activities.

Table 2

Types of geometric ideas that were used by the EQ program participants along with sample quotes from these participants.

Geometric ideas	**Sample participant quotes**
Center	"Fold 1 edge of square to crease in center"
Half	"Fold cardstock paper in half"
Intersect	"Move the top left corner to where the previous 2 creases intersect"
Parallel/perpendicular	"Parallel lines"
Proportion	"Elongated hexagon"
Symmetry	"Make sure it's even on the top and bottom"

Reference points were language that the participants used to describe features in relationship to one another. Examples of this idea included "over/under," "top/bottom," "inside/outside," "front/back," and "apart/together." Table 3 provides some examples of different types of *reference points* and corresponding quotes from the participants as they used *reference points* in the context of the program activities.

Table 3

Types of reference points that were used by the EQ program participants along with sample quotes from these participants.

Reference points	**Sample participant quotes**
Apart/together	"All four corners folded together"
Front/back	"From the front why do we only see three blocks instead of four?"
Inside/outside	"Flaps on the outside"
Over/under	"Fold the paper over itself"
Top/bottom	"Top right corner onto bottom left corner"

Use of origami terminology

Participants also used different kinds of origami terminology as they engaged in the program activities. They used terminology as they were defined in the vocabulary lists that they received as part of the materials kit as well as using their own interpretations of definitions for certain words. A list of the vocabulary words that were provided to the students is presented in Table 4 in Appendix A and includes terminology such as "mountain fold," "valley fold," "cupboard fold," and "tessellation."

For example, one participant instructed their peers to "make a valley fold towards me in the middle." The students' vocabulary list defined a "valley fold" as being "formed by folding paper towards you and over another part of the paper." This student demonstrated that they knew the definition of a valley fold as it was given to them and were able to apply this definition to communicate how to create this type of fold to their peers.

There were also instances of the participants using origami terminology in their own words as opposed to using the words as they were defined in the vocabulary list. For example, participants used the word "fold" as a verb (as presented in the vocabulary list) synonymously with the word "crease" as a verb, which was defined as a noun in the vocabulary list. One participant said to "crease [the paper] in other directions" when referring to making a fold in the paper. Another participant said to "crease the fold," indicating to make a fold as defined in the vocabulary list. This example also reveals how participants also used the word "fold" as a noun synonymously with "crease" as a noun (as presented in the vocabulary list).

Participants also demonstrated instances of using the word "crease" as a noun (as defined in the vocabulary list) synonymously with the term "folded edge." This phrase was defined in the vocabulary list as "an edge where a fold creates two layers of paper." One student referred to the folded edge of a piece of paper as a "crease" when describing a particular shape that they had been folding. Another student commented that they had "confused the crease and the folded edge" when identifying different line types in engineering drawings. The crease and the folded edge were represented using different lines in a drawing, but this student's confusion likely arose from them conceptualizing the crease and the folded edge as the same construct and thus assuming the line type used to represent these different elements would be the same.

Preference of specific, succinct instruction

Results also demonstrated that the participants valued *specific, succinct instruction* as part of the EQ program activities. For example, some participants indicated specifically that *concise instruction* was beneficial to their learning. When asked what types of words were helpful to the student when interpreting written origami or engineering drawing instructions, one participant said that "[describing] and [using] words efficiently and concisely" was helpful. This student said that when instructions were too long or wordy, they would "pick apart each word" and "spend a lot of time" dissecting the instructions they were given, so having "concise instructions [was] better" for this student's understanding during the activities.

Similarly, EQ participants indicated that *specific instructions* were helpful. Such instructions included using words that specifically indicated what the *final shape* after completing a particular origami fold should look like. For example, one participant instructed to "fold [the paper] in half so it makes a triangle." Another participant said, "it should be like a rectangle with three raw edges on the top, left, and right" when asked what their paper would look like after performing a particular fold.

Participants also said that it was helpful to have *multiple descriptions* when receiving instructions. For example, one student commented, "it helped when something was described in more ways than one, folding east to west or left to right."

Use of different types of strategies

Results indicated that the EQ program participants employed different strategies to ensure their success in completing the program activities and mitigating challenges. The identified strategies included *different types of preparation*, *cognitive strategies*, *tactile strategies*, and *analytical approaches.* These strategies helped mitigate certain *challenges* that the participants experienced throughout the program. Some types of *challenges* that the participants identified included the *difficult format* of the virtual program, *difficulty understanding the terminology* used throughout the program, and having *difficulty visualizing diagrams or models in two and three-dimensions.* The following sections describe each of the strategies and how the participants used them when they were met with challenges during the program.

Level of preparation

Some participants entered the EQ program with levels of prior knowledge about origami, engineering drawings, or STEM concepts in general. One participant remarked that he had taken a STEM-focused class in his high school where he had completed some technical drawing assignments as part of the course. He said that he "had no idea how to possibly do [it]," so he had someone else do those assignments for him. After completing the EQ program experience, he said that he now has "a better idea of how to actually do it for [himself]," and that he feels that he is more prepared to enter a career in STEM. Another student said that they were "familiar with a good amount" of the words that were used during the program sessions, but that "there was still a good amount that was new." They also commented that they "already knew some of the origami" terminology and types of folds.

For other students, this program was their first exposure to the STEM concepts presented. One student said that a lot of what she learned through the EQ program was how to describe things in the most effective way, using new words that she had learned. She said that learning new types of spatial words and vocabulary helped her with the final project that she worked on for the program: creating a pop-up book. She remarked that she had wondered about the mechanics of pop-up books, but until engaging in the EQ program, she had never made one on her own. Other participants indicated they were familiar with some of the concepts introduced in the EQ program, but these concepts were applied in different ways than they had experienced before. For example, when asked about their level of familiarity with the vocabulary that was used during the paper folding activities, one participant responded, “I think I understood the words but they got appropriated for different things like the meaning of them changed a little bit.”

The last type of preparation that was observed was how participants chose to prepare for the different sessions that they engaged in. Students discussed how they would use what they learned in previous sessions of the EQ program to help them complete activities in a later session. One student said that they had “done a lot of practicing with the folds and stuff like when we actually made the [masu] box on Friday, so that made it very easy to just create the drawing that would go along with that.” Similarly, another student commented that “having had assembled the model before the session gave meaning to the words.” Working with the origami models on their own time helped solidify the content that they had learned during the synchronous instruction sessions.

Cognitive strategies

Participants in the EQ program demonstrated the use of *cognitive strategies*. For example, participants indicated that they generated *mental images* that allowed them to *visualize in two or three dimensions* as they were engaging with the program activities. During one session of the drawing activity, students were prompted to look at a drawing of a cup from a particular view and identify how the handle of the cup would be represented in two dimensions. One student responded, “the two lines in the middle on the inside of the cup are the grip.” Another activity required students to visualize how a three-dimensional object, such a sphere, would be represented in two dimensions. One student responded to this prompt by saying “use a circle” to represent a sphere in two dimensions.

Participants also described features in terms of *basic shapes.* This strategy was evident when the participants recognized or identified basic shapes including squares, rectangles, triangles, or circles. Students made comments such as, “cut out a circle in the middle of the oval you cut,” and “fold the cut edges up to look like [a] triangle shape.” Participants also used *comparative terms* when describing certain spatial features. This was evident when the participants described a feature, model, or shape in terms of something else. For example, participants made comparisons such as saying that the “paper looks like an ‘X’,” the shape would resemble a “‘J’ pointing left,” or gave an instruction that said the fold was “kinda like you were making a paper airplane.”

Other students employed *intrinsic-dynamic* and *extrinsic-static* skills [25]. *Intrinsic-dynamic* skills involve mental transformation, such as mentally folding or rotating [26] an object. An example of this skill was evident when one student described an instruction for how to fold their model: “You open the paper and fold out and crease in the middle line, and this makes the egg and it'll pop out.” *Extrinsic-static* skills involve understanding the spatial relationships between objects [26]. For example, one student indicated a description of folded paper as being a “square with triangles touching.”

Tactile strategies

The EQ program participants also used *tactile strategies* to interpret and understand information. This type of strategy was observed when participants used their hands or fingers to interpret or analyze a shape, model, or drawing. For example, one participant indicated that they would "[feel] crease lines" when they were performing various paper folds. Another said that the origami and technical drawing patterns were easier to understand if they "could use it tactually" and "feel it," like "the actual folding of the origami" or "using the snap cubes" for the engineering drawings.

Analytical strategies

Last, the EQ program participants used certain *analytical strategies* when completing the origami and drawing activities. These included *counting features* (e.g., "crease lines through the rectangle with three raw edges"), using *measurement terms* (e.g., "in the middle of the paper put two parallel lines two inches right from the middle"), and performing *calculations* (e.g., "[I] did calculations for the lid and how it fit").

Relationships among types of spatial language

Results also showed that certain types of spatial language were associated with one another. For example, students who were *prepared for the activities* also *learned from those activities.* Preparing for the activity included engaging with the asynchronous materials before the next synchronous session. One student commented that the work that they did during the activity "made a lot more sense" as the instructor was explaining it "just because there was some stuff that we'd go over before we did the session that just made it easier." In another instance, preparing for the session activities included completing an origami model before attending the next synchronous session. One participant said that "having had assembled the model before the session gave meaning to the words."

Other findings suggested the importance that words related to *symmetry* had on how the participants used spatial language during the paper folding and drawing activities. The participants described origami folds such as the *cupboard fold* using *symmetry.* One student gave instructions to "fold the sides of the paper to the middle fold of the paper as a cupboard fold." Another student described how the previous fold that they had made should result in "one card with a flap on each side." Symmetric features were also used to describe *location* when giving instructions. One student gave instructions that said, "in the middle of the paper put two parallel lines two inches right from the middle." This example also demonstrates how students used *measurement terms,* such as specifying a distance between two portions of a model, along with symmetric features.

Last, findings suggested that *hands-on learning* helped students *learn from the activities.* One student described how they were provided with tactile drawings of different types of lines that were used for engineering drawings. They said that having those tactile drawings "made it a lot easier to know what the various lines were supposed to look like and things." They further emphasized that having those tactile drawings "made it pretty easy to recreate those and make the diagram using those fold and crease lines and things."

Discussion

There are limited studies that have explored the spatial ability and spatial language of BLV students. Similarly, there is little research that has explored the types of spatial language that BLV students use when engaging in origami activities. This study provided initial insights into different types of ways that BLV youth used spatial language while completing a summer engineering program online. The impacts and insights gained about conducting this program online in a virtual format is discussed and presented in another paper by the authors [27]. Findings from this study also revealed different strategies that the BLV participants used when engaging in the program activities and how they mitigated any challenges that they faced. Last, this study revealed relationships between types of spatial language that the participants used throughout the program. It is important to note that the purpose of this study was not to compare vocabulary use and meaning of blind learners with those who are sighted; including a comparison group of spatial language used by sighted learners was beyond the scope and feasibility of this study. In addition, the results of this study are not intended to be generalizable to other populations. This work provides an initial, exploratory insight into how BLV students who participated in the EQ program used spatial language during the program activities. Future research could explore spatial language use beyond these participants in both BLV and sighted populations.

Use of spatial language

The results of this study provided insights into different types of spatial language used by BLV high school students as they completed origami and engineering drawing activities. These types of spatial language included describing *geometric ideas*, *reference points,* and *directional words*. Research has indicated that spatial language can support spatial reasoning skills [28]. In a previous study of BLV students, Argyropoulous [29] found that BLV students leveraged spatial language, touch, movement, and prior knowledge when conceptualizing geometric shapes. This finding supports the results of the present study, in which the research team found evidence of the BLV participants using spatial language, including words describing geometric features. In addition, directional words, such as cardinal directions, are frequently used by BLV populations to navigate or orient themselves in space [30]. The results of this work support this idea and reveal the importance that this type of language has for BLV individuals who are completing tasks that require the use of spatial ability. By encouraging BLV youth to use spatial language and by teaching them different types of spatial language through guided activities, their spatial reasoning and/or spatial ability skills may be able to be strengthened. In addition, educators may benefit from understanding how BLV students conceptualize spatial concepts and the language they use to do so as they develop learning materials that are accessible to these populations. Future studies could elaborate on these initial results by investigating the complexity of spatial vocabulary used by the participants or the frequency in which the participants used spatial language to understand the impacts these may have on students' understanding of spatial concepts.

Use of origami terminology

This study involved observing BLV high school students as they participated in an online engineering experience where they engaged with origami and engineering drawing activities. Previous research has highlighted how origami and paper folding activities can be used in educational settings to support students in developing abstract reasoning skills, fine motor skills, and spatial visualization skills [31]–[33], as well as for targeting spatial ability [34]. However, there has been little research conducted to understand how origami instruction can impact the spatial ability of BLV individuals. In turn, there is limited research that explores the type of language that BLV students use when participating in origami activities. The present study aimed to fill this gap by providing insights into how BLV high school students used common origami terms, such as “mountain fold” and “valley fold,” as well as different types of spatial language, such as *geometric ideas* and *reference points,* to complete origami activities. Results showed that the BLV participants used origami terminology as they were defined in their provided vocabulary lists (shown in Appendix A) as well as using their own interpretations of certain words, such as using the word “crease” synonymously with the phrase “folded edge.”

Understanding how BLV students use, interpret, and make meaning of origami terminology can help educators develop relevant and engaging origami and paper folding content for BLV audiences. Origami activities may help BLV populations refine their spatial ability and spatial visualization skills while providing them with a creative outlet to create an artifact of personal interest to them.

Preference of specific, succinct instruction

This study revealed the importance of specific, succinct instruction for the participants in the EQ program. This finding provides an initial insight into ways that BLV youth receive and interpret spatial information. By providing concise instructions that are easy for BLV students to understand, they may be more successful in completing spatial-related activities. When facilitating large groups of students or students in a virtual environment, having specific instructions that detail how a particular origami shape should look upon completion of a fold can help mitigate the amount of students who fall behind because they missed a step. In addition, specific instructions can help clarify how to complete certain steps in the folding process, limiting the amount of students whose origami models are incorrectly completed. This is especially true for online programming, as a virtual environment can be a disadvantage for students as they are unable to get hands-on feedback on the folds they are performing in real time [27]. In addition, providing multiple methods of description may help more BLV students connect with a particular idea and relate it back to their prior knowledge about a certain topic or how to perform a particular task. One student may relate more to an instruction describing a fold being done from “east to west,” while another may understand this instruction better if it were described as being done from “right to left.” Educators should remain open to using multiple ways of describing spatial information to ensure a broader range of student conceptualizations are accounted for.

Different types of strategies for success

The results of this study revealed that the EQ participants used different types of strategies, such as tactile, analytical, or cognitive, to ensure their continued success throughout the program and to mitigate challenges they may have experienced. These challenges included navigating the *difficult format* of the virtual program, having *difficulty understanding the terminology* used in the origami and engineering drawing lessons, and experiencing *difficulty visualizing diagrams or models in two and three-dimensions.*

The study results demonstrate the importance and viability of these strategies for those in the BLV population. The importance of tactile strategies in particular was also found in Argyropoulos's [29] study of how BLV students gain experience about geometric shapes. Their study found that tactile experiences, such as feeling cardboard cutouts of different types of shapes, were integral to how BLV students conceptualized geometric shapes and their features (e.g., sizes of angles and lengths of lines). In the present study, participants in the EQ program commented on the ways that they used tactile methods, such as feeling crease lines that were imprinted on a folded piece of paper or using three-dimensional manipulatives to understand the representation of a two-dimensional drawing. They implemented these strategies to interpret geometric and spatial information and perform various tasks throughout the program activities. This finding is expected, as BLV populations commonly use tactile methods for acquiring information and learning. This finding was also expected because the materials that the students were provided with were all represented in tactile formats (e.g., tactile graphics, Braille, and tactile drawing tools). It was therefore expected that the program participants would utilize tactile strategies when engaging in the activities. Additionally, the instructors of the EQ program, many of who were blind, modeled tactile strategies to the participants.

Instructors and educators should leverage various types of strategies, such as tactile, that are used by BLV students and strive to incorporate elements of these approaches into educational materials for the classroom. Encouraging BLV students to make use of strategies that are useful to them can help these students feel empowered to overcome challenges they may experience throughout their education.

Relationships among types of spatial language

Last, this study provides preliminary insights into relationships between how BLV high school students use spatial language and the ways they use different types of spatial language in combination with one another. One example that was presented in this paper was the relationship between being *prepared for the activities* and *learning from the activities.* The results from this study suggest that students who were more prepared to engage with the content of the activities also found that they were able to learn more from them. Students prepared for the activities in various ways, such as doing the asynchronous activities before the next synchronous session (e.g., watching videos, reading articles, or solving tactile puzzles) or working on their origami projects on their own time.

Another example was the relationship between how the program participants used *symmetry* with other aspects of spatial language, such as describing *location*. Participants used language describing different origami features in terms of symmetry, such as describing how to fold edges of a piece of paper to the middle, talking about certain features that should mirror each other across the center of the paper, and ensuring that two portions of folded paper were even with each other.

In addition, the *hands-on learning* opportunities in the EQ program helped the participants *learn from the activities.* An example that was presented in this paper was a student who commented on the effectiveness of having tactile drawings of different line types used in engineering drawings. This participant highlighted the importance that this aid had on their learning; having the tactile drawing made it easier for them to create their own version of the engineering drawing pattern. This aid also supported them in knowing how and when to make different types of lines to represent certain features, such as folded lines and raw edges. This finding is notable because blind students typically do not have access to diagrams, since these types of aids are primarily presented in visual formats. In addition, having access to an example drawing made it much easier for the students to create drawings of their own. When teaching sighted populations how to create technical engineering drawings, visual examples are provided to demonstrate line types and different views of the object (e.g., front, top, right). Blind populations, however, may be expected to recreate engineering drawings (or other artifacts that are traditionally represented visually) without being provided examples in formats that are accessible to them.

Conclusions

In order to encourage participation in engineering from BLV populations, engineering experiences for this group should be improved. This study provided insights into the types of spatial language that BLV high school students used as they engaged with origami and engineering drawing activities. Findings from this study can inform future development of engineering activities for BLV students by incorporating types of spatial language that are relevant to this population.

Interventions that encourage BLV individuals to use spatial language and engage tactually with content designed to improve their spatial ability should be promoted. This study highlighted one example of an experiential program designed to engage BLV high school students with engineering content tactually through paper folding and engineering drawing. Educators should understand the types of spatial language that are used by BLV individuals and recognize that many types of educational content in STEM are not designed with BLV individuals in mind. Recognizing the ways in which this population uses spatial language and spatial information is one way that content designed for targeting spatial ability can be tailored to incorporate perspectives from BLV populations.

By understanding more deeply how BLV individuals use spatial language when engaging with tactile activities, STEM content can be designed to be more inclusive for all populations. Providing BLV students with opportunities to engage with STEM content may also encourage more students from this population to pursue engineering pathways or endeavor to develop engineering and technical literacy. The results of this study provide a preliminary understanding of how this population uses spatial language and can inform future curricular efforts going forward. This work will also inform the development of future offerings of this engineering program offered by the NFB to continue to encourage BLV youth to engage with STEM content.

Future work can use the results of this study to compare how spatial language is used by BLV populations compared to sighted populations. Future work could also leverage these findings to study other aspects of spatial ability in BLV learners, such as exploring differences in spatial ability among genders, impacts of using origami to prepare students to learn engineering concepts, or the effect of different engineering activities, other than origami or drawing, on spatial ability.

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Appendix A

Table 4

List of origami vocabulary words that were provided to the engineering program participants in the activity kits that were mailed to them.

Fold	Definition
Crease	The line that results from folding and unfolding paper.
Fold	To bring two parts of a sheet of paper into contact and then flattening the paper to make a sharp edge.
Valley fold	Formed by folding paper towards you and over another part of the paper.
Mountain fold	Formed by folding paper away from you and underneath another part of the paper.
Model	A completed origami project.
Raw edge	An edge that has not yet been folded.
Folded edge	An edge where a fold creates two layers of paper.
Crease pattern	When you unfold a model back to a flat piece of paper you can observe the crease lines that result from the various folds. This pattern is called a crease pattern.
Diagonal fold	A fold that results from folding one corner to meet the opposite corner, creating a diagonal crease across the paper.
Modular origami	A type of origami where many sheets of paper are folded into often identical units or modules. These units are then slotted together to form larger geometric designs.
Tessellation	An arrangement of shapes, particularly polygons, closely fitted together in a repeated pattern without gaps or overlapping.
Base	A combination of folds that can be used as a starting place to create various models.
Cupboard base	The result of folding left and right hand edges to a central crease. The resulting model resembles a cupboard.