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Advantages and Disadvantages of a Virtual Engineering Experience During COVID-19 for Blind and Low-Vision High School Students

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Introduction

The purpose of this research paper is to explore advantages and disadvantages of conducting an engineering experience for blind and low vision (BLV) participants in a virtual/online environment. This experience was designed to expose BLV high school students to engineering content and enhance their spatial ability. Spatial ability is an intelligence generally defined as the ability to generate, retain, retrieve, and transform well-structured visual images [1] and is particularly important to fields of science, technology, engineering, and math (STEM). A variety of spatial ability constructs have been identified, a few of which include mental rotation, spatial orientation, and spatial visualization [2], [3]. This paper refers to spatial ability as a quantification of performance on a specific construct of spatial thinking: rotation and cutting plane.

Many studies have shown that spatial ability is a positive predictor of student success in a wide array of academic studies. Of particular interest is the correlation between student success in STEM fields and high spatial ability [4]–[6]. Additional studies have shown that professionals in STEM related fields also benefit from an aptitude towards spatial thinking [7]–[9]. Furthermore, research has shown that spatial ability can be effectively taught and learned through targeted interventions [10]. An analysis of the effects of spatial ability on students and professionals in STEM fields demonstrates the need to encourage spatial development in scholastic and other settings. One factor that may influence the extent to which STEM students develop spatial skills is the format in which courses are delivered. One study has shown that undergraduates' participation in an in-person engineering statics course yielded a significant increase in spatial ability over a four-month period [11]. Another possible avenue of instruction is through virtual formats utilizing synchronous and asynchronous online teaching sessions. A study conducted to determine the effectiveness of web-based spatial training using mobile devices found that participants who engaged in the online course increased in spatial ability and preferred the online format over traditional face-to-face courses [12].

The wide transition from face-to-face to online class formats associated with the COVID-19 pandemic has highlighted both advantages and disadvantages to collegiate learning in virtual settings. Online and blended courses have gained popularity in recent years likely due to the added flexibility online courses offer, allowing students to work at their own pace and repeat material as needed [13], [14]. Research has shown that online and blended instruction provide similar student learning outcomes as traditional in-person classes at a lower cost [15], and perhaps most importantly, online courses make education available to a larger number of students who otherwise may have been unable to attend in-person [16]. On the other hand, studies of virtual classroom effectiveness during the COVID-19 pandemic have reported lower levels of student discipline in completing assignments and less motivation to participate in discussions [17]. When students participated in online classes over extended periods of time, many reported a negative impact on their mental and physical health [18], which can adversely affect learning outcomes. Moreover, the literature indicates that the online learning perpetuated by the COVID-19 pandemic was frequently inaccessible to BLV youth due to the use of inaccessible technologies and exclusionary pedagogical practices [19].

Consistent with the growing popularity of online education among the general population, the number of students with disabilities enrolling in online education has also increased [20], and is expected to continue to increase [21]. This is likely due to the enhanced accessibility online education offers. Many BLV students benefit from online courses because of the absence of physical barriers such as buildings, large campuses, and lack of accommodations [22]. However, online classes are not void of inaccessibility by nature. Pavithran reports that factors influencing BLV accessibility in online courses include lack of instructor training, lack of monitoring and accountability, and inequities in access to bandwidth infrastructure and devices [20]. Many courses are designed without accessibility in mind which can be detrimental to students with disabilities. It is far simpler to begin an online course with accessibility in mind than to scramble to make adjustments when a student with disabilities enrolls [23].

One online program that was fundamentally designed with accessibility for people in the BLV community in mind is the Engineering Quotient (EQ) program administered by the National Federation of the Blind (NFB). This program was administered virtually online for four weeks during the summer of 2021. The purpose of this paper is to explore advantages and disadvantages of holding this engineering program online to teach spatial ability to BLV high school students. The insights presented in this paper are part of a larger study exploring how BLV students used spatial language throughout the activities in the EQ program [24]. Traditionally, the EQ program is held in-person at the NFB's headquarters in Baltimore, Maryland, where students engage in STEM-related activities and projects and interact with fellow BLV peers. This program was adapted for online facilitation during the summer of 2021 as a result of the COVID-19 pandemic. Findings from this study provide considerations for the NFB's future offerings of the EQ program. By more deeply understanding the challenges and benefits associated with different modes of delivering STEM content to BLV students, educators can be more informed about developing STEM programming for BLV students that may eventually encourage them to develop interest in STEM fields in the future.

Methods

Engineering program overview

This study explored data that was collected during synchronous Zoom sessions of the EQ program, the NFB's virtual online engineering experience, which occurred over four weeks during the summer of 2021. The activities of the summer 2021 EQ program focused on teaching participants about spatial thinking and spatial ability skills through lessons about creating origami/paper-folded models and constructing engineering technical drawings. Prior to the start of the EQ program, all participants were mailed kits containing materials that they would need to complete the activities during the sessions. This included supplies such as workbooks, tactile instruction boards, raised-line drawing boards, origami paper, straight edges, ball styluses, and writing utensils.

Synchronous sessions of the program were held weekly on Mondays, Wednesdays, and Fridays throughout the four-week duration of the program. These sessions included one hour of guided instruction on paper folding/origami, a 30 minute break, and another hour of instruction on engineering drawings. Participants were split into two groups with one group attending the paper folding/origami sessions first and the other group attending the drawing sessions first. After the 30 minute break, the groups switched sessions to complete the session they had not started with.

Participants were also encouraged to engage with asynchronous activities on Sundays, Tuesdays, Thursdays, and Saturdays that were supplemental to the guided synchronous sessions. These asynchronous sessions included opportunities to "engage," "practice," and "extend." "Engage" activities were intended to be completed on Sundays before the rest of the week's sessions. These included links to videos and articles that aimed to introduce and motivate the topics that would be covered during the guided instruction throughout the week, such as interviews with blind professionals working in STEM or techniques for completing origami projects nonvisually.

"Practice" activities were intended to be completed after the synchronous sessions on Mondays and Wednesdays. These activities utilized materials that were included in the participants' kits that were provided to them. For example, one week's "practice" required participants to use what they learned in the synchronous session about paper folding and engineering drawing to independently complete another paper-folded model and drawing. Participants were then asked to reflect upon their attempts at creating these models and bring their thoughts to the next synchronous session.

Last, "Extend" activities were intended to be completed after the synchronous sessions on Fridays. Participants were encouraged to use what they learned throughout the entire week to complete a new activity related to paper folding, drawing, or spatial ability. For example, one week, students were required to follow instructions about creating their own pop-up book using materials provided in their kits. Another week, they folded a new origami model that was not covered in the guided instructions.

Participants and data collection

Participants in the EQ program included BLV youth in the United States who were in grades 9 through 12 during the 2020-2021 school year. There were a total of 35 BLV youth enrolled in the program. Prior to beginning the program sessions, participants and their families were sent an IRB-approved informed consent letter that allowed them to opt in or out of the research activities. Data was collected only from participants that acknowledged their consent or assent to opt in to the research activities. Out of the 35 BLV youth enrolled in the program, 13 provided parental consent or individual assent to participate in the research study.

The research team consisted of five members, including three researchers in engineering education and two researchers from a STEM research and evaluation center. The research team members observed at least one synchronous program session per week throughout the duration of the program. Some researchers observed the same sessions at the same time and others observed different sessions on their own. This allowed for a variety of perspectives from each of the research team members to be captured. Each of the researchers followed an observation protocol in which they captured spatial language that the participants used while completing the paper folding and drawing activities, as well as the context in which they used the words and the possible meaning behind these words. This protocol was developed in accordance with the goals of the larger investigation to understand how the BLV participants used spatial language while completing origami and engineering drawing activities [24].

The research team solicited interviews from the consenting participants during their 30 minute break in between the paper folding and drawing sessions. If the participant agreed to partake in an interview, the researcher and the participant then moved into a separate breakout room on Zoom. Each interview lasted between three and ten minutes. Prior to asking questions, the researcher asked for the participant's consent to record the interview so it could be transcribed later. In addition to asking questions that were targeted to understand how the participants used spatial language, the researchers asked questions to glean insights into the participants' experiences participating in the online EQ program. They asked questions such as, "What do you think are the advantages and disadvantages of doing this kind of program online?" and "What kind of things were most difficult for you during the paper folding or drawing sessions?"

Data analysis

Data sources included field notes from observations of the synchronous sessions and interview transcripts from interviews solicited from consenting participants. These data sources were analyzed using qualitative coding procedures [25] to identify themes related to the spatial language the participants used during the program as well as their overall experience participating in the EQ program virtually.

Field notes and interview transcriptions were first coded using first cycle coding methods [25] using MAXQDA, a qualitative analysis software [26]. Two of the research team members independently coded the entire dataset to identify types of spatial language that the participants used during the program. Origami words and terminology that were provided to the participants in their kits of materials were also used as a priori codes [25]. The two research team members then held meetings to discuss the identified codes. The team members refined and adjusted the codes and their applications until an intercoder agreement of 90% was reached. During the second cycle of coding, the two team members identified axial codes that represented broader themes to categorize the first cycle codes [25]. After exploring the resulting themes about spatial language used by the participants, discussed in another paper [24], the team then looked for evidence of the participants describing the advantages and disadvantages of the online EQ program experience.

Results and Discussion

Results from the first and second cycles of coding provided insights into the spatial language used by the program participants as well as their overall experiences participating in the EQ program virtually. Types of spatial language that the participants used included describing geometric features (e.g., center, half, parallel), using directional words (e.g., left, right, east, west), and using reference points (e.g., apart/together, front/back, top/bottom). A full description and analysis of the spatial language used by the students in the EQ program is presented in another paper by the authors [24]. In addition to developing an initial understanding of the types of spatial language that BLV students use when engaging in origami and engineering drawing activities, insights into these students' experiences with the online EQ program format were also developed. Analysis of the participants' responses to the interview questions revealed that they felt that there were both advantages and disadvantages to engaging with the EQ program online. Advantages included having increased flexibility to complete the program activities; broadening the participation of people able to participate in the program; and providing access to resources that may have otherwise been unavailable. Disadvantages included a lack of tactile, hands-on feedback for the participants; difficulty in following instructions; and a lack of opportunities for social interaction among the participants. This section describes each of these advantages and disadvantages and describes ways that the facilitators of the program attempted to mitigate the disadvantages.

Advantages

There were several advantages to the online format of the EQ program that were mentioned by the participants. These advantages included having flexibility in attendance and access to the program; the ability for increased participation by a broad population of students; and an increased access to resources. Considering these advantages may provide insights into how programming for BLV youth is developed in the future.

<u>Increased flexibility.</u> One of the advantages mentioned by the participants was that the virtual format of the program allowed them the flexibility of participating in the activities from anywhere and at their own convenience. For example, during an interview, one participant said,

> "I think the advantages are that you can do it from anywhere. Anywhere, where you're at. So like right now I'm technically not at my house, I'm actually doing this while I'm at another summer program, and so that makes it – that's one definite advantage is that I can do this during the parts of the day that I do that and do all my other stuff I'm working on the rest of the time."

This participant described how they were also engaged in another summer program that was happening at the same time as the EQ program. They noted that because the EQ program was virtual, it allowed them the flexibility to simultaneously participate in the other program that they were interested in. This participant also mentioned that they were not at their home location while they were attending the EQ program. Because the EQ program was conducted completely online, participants were able to engage with the program activities whether they were in their own homes or if they were elsewhere.

This finding aligns with previous research [27] where BLV participants noted that an advantage of online learning was the increased flexibility it provides. Participants in the virtual EQ program indicated that they were involved in other summer programming, had family obligations, or were traveling during the weeks of the summer that the EQ program was taking place. The virtual program format and the option for the asynchronous activities allowed the participants to access the program regardless of their physical location.

Broadening participation. Additionally, the virtual nature of the EQ program experience allowed for the potential of broadening access for individuals who may otherwise have been unable to attend the program. In the past, the EQ program has been offered in-person at the NFB's headquarters in Baltimore, Maryland, requiring participants to travel by air or car in order to participate. By offering the EQ program online, participants did not have to make travel arrangements and were able to complete the program from the comfort of their own environment. As a result, a broader range of BLV individuals may have been more encouraged to apply to participate in the EQ program, knowing that the activities could be completed from the comfort of their home and without the potential logistical strain of traveling, removing potential limitations based on physical barriers.

Access to resources. Participants described how another benefit of the online format of the EQ program was that they were able to use technology to their advantage. Participants indicated that they had more access to information since they were able to use a computer and use the internet during the program. This contrasts the experience participants may have had if they had conducted the EQ program in-person; in an offline setting, students would complete activities using resources provided to them on-site, which may or may not have included access to computers on an individual basis. The virtual program afforded participants with access to more resources through the internet than may have been available if the activities were conducted in person. Students accessed the synchronous program sessions using Zoom on a device of their choosing, such as their phone, tablet, or computer. Some students indicated that they used their devices and the internet to learn more about certain topics or clarify information that was presented in the sessions. Several students also used the internet to their advantage when completing their final project at the conclusion of the program. For example, students used web development tools to create their own websites with origami instructions and descriptions. This type of project allowed students to be creative with their final project in a way that let them use technology and the internet to accomplish their goals. This type of idea for a final project may not have arisen during in-person offerings of the engineering program and demonstrate how BLV youth used technology to their advantage in this virtual program.

Disadvantages

There were also several disadvantages mentioned by the program participants that suggest considerations for educators as they develop virtual programming for BLV populations. These disadvantages included a lack of hands-on assistance and tactile feedback from the instructors; participants having difficulty following instructions in a synchronous online space; and a decreased ability for participants to interact socially with one another. Insights gained from these challenges and methods for overcoming them provide valuable information for program directors who look to develop BLV activities, especially activities that may look to provide opportunities for learning in similar situations to the COVID-19 pandemic.

Lack of hands-on assistance and tactile feedback. The primary disadvantage of conducting this engineering program virtually was the inability for instructors to provide hands-on assistance and tactile feedback to the participants. In an in-person setting, instructors would be able to move around the classroom to provide help and guidance on performing folds and working on drawings. Participants mentioned that because the EQ program was virtual, they were unable to have instructors help them perform folds or check the accuracy of their folds or drawings. They were also unable to get immediate feedback on folds they were performing as instructions were being given; if participants missed a step or misunderstood a step, it was difficult to for them to catch up or explain to the instructor where they fell behind.

One student commented that "it's been a little difficult to understand things, especially with the origami and stuff." The student suggested that when they had trouble understanding something related to the activity, it would have been helpful if the instructor were able to be there in person with them to "feel what we're doing" and "tell us this is where you're messing up." They said, "[…] a lot of times online, it becomes kind of difficult to do that. And so you're kind of stuck being like, you're finding your own resources and things you can understand for yourself trying to figure it out." Another student had a similar experience, indicating that because the program was online, "it was a lot harder to get help on a couple things just because, you know, someone couldn't show up to you like more hands on if you needed to."

The sentiments of both of these students reflect the difficult nature of receiving help in an online program, particularly when activities rely on tactile elements that are difficult to describe and interpret without feeling them in person or receiving hands-on help. Another student said that "there's not a great way to describe some of this stuff without being able to feel an example of it" when they were having trouble following the steps to complete a particular origami model. To mitigate this challenge, one participant suggested that after each step that was being described, the instructor could prompt the students by asking if the instruction was clear or if there were any questions before proceeding to the next step.

Additionally, limitations in software prohibited instructors from providing tactile feedback to the participants as they engaged in the paper folding and drawing activities. Through Zoom, sighted populations could utilize the video sharing feature to share and receive visual feedback on paper-folded models. However, Zoom does not allow for the tactile sharing of information, thus limiting the type of feedback that participants in the EQ program could receive. For example, participants were unable to compare their final paper-folded models to those created by the instructors. The instructors had to ensure the language they used to describe the shapes and folding instructions was very clear and easy to interpret. However, verbal instructions could easily be unintentionally misinterpreted, resulting in incorrect models or drawings and providing little opportunities for correction or clarification.

One way the EQ program attempted to mitigate these challenges associated with the lack of hands-on assistance and tactile feedback was through materials that were included in the participants' kits. For example, the kit included an instructional board that had tactile representations of how the masu box should look after each stage of the folding process. This was to provide guidance to the participants by allowing them to compare their folded models to the instructions and to help them visualize what the correctly folded model should like. Additionally, the kit contained a raised-line drawing tool. As participants drew lines on paper with a pen or stylus, a raised tactile line was generated that followed their hand-drawn lines. By using this tool, participants could get tactile feedback on the drawings they created during the program activities. These are examples of methods that educators may use to provide BLV students with opportunities for tactile feedback in a virtual online environment.

Difficulty following instructions. Another disadvantage that the students mentioned was that it was occasionally difficult to follow along with the instruction during the activities. During one of the engineering drawing sessions, a student said that it was “a little bit unclear when we were supposed to switch over to a new sheet of paper or when we were supposed to start drawing in a new area. That kind of thing wasn't very clear.” Another participant voiced a similar perspective, saying that “when it comes to paper folding and you miss a step or two…that’s a challenge.” The virtual nature of the program required the participants to follow along with the instructors’ guidance without any tactile feedback from the instructors. This was due to the limitations of current software and hardware, which did not permit direct tactile feedback from remote instructors. When the EQ program was administered in person, tactile feedback provided to participants by instructors was a large part of the activity facilitation. In the virtual environment, there was no opportunity for this kind of interaction between participants and instructors; Zoom does not have functionality that allows for tactile feedback. If a participant missed a specific instruction, fell behind while completing a step of an activity, or needed assistance performing folds or completing drawings, it may have been difficult for them to receive the help and guidance they needed.

Lack of opportunities for social interaction. Last, students in the EQ program identified that a disadvantage of the online EQ program was that it limited their ability to interact socially with other participants. One participant mentioned that they would have liked to have more opportunities to talk casually with others in the program. They said that it also would have been helpful to be able to discuss details of how other participants completed certain portions of the activities and gain perspectives and insights from their peers. During the in-person offerings of the EQ program, social interactions between participants were more naturally facilitated. Participants were gathered in the same room seated next to one another or in groups as they received instructions and completed activities. Participants also had opportunities to explore the local area and engage in recreational activities after finishing the formal program activities for the day. Fostering these types of social interaction is more difficult in an online space, where the activities were more structured and interactions with others was most often limited to the participants’ time spent in the synchronous sessions.

The EQ program attempted to mitigate this disadvantage by encouraging the participants to interact with one another during the 30-minute break time between the drawing and paper-folding instructional sessions. During these 30-minute break sessions, multiple breakout rooms on Zoom were available for students to join. These breakout rooms included monikers such as a “coffee shop” room, a “garden bench,” or a “hallway,” and were intended to be used as informal gathering spaces for participants to talk with one another casually about topics outside of the EQ program activities. Some participants used these rooms for this purpose and were found to be discussing shared hobbies and interests with one another, while other students used these rooms as a shared quiet space to take a break between activities. While social interaction may be difficult to foster naturally in an online space, offering students opportunities to engage with one another, such as through breakout rooms during break times, may help mitigate this disadvantage of online learning.

Conclusions

This study provided an overview of participant-identified advantages and disadvantages of conducting an engineering learning experience for BLV high school students in a virtual online format. The EQ program administered by the NFB was designed to provide blind youth with an introduction to engineering and STEM content, encourage interactions with other BLV peers, and improve problem-solving abilities. This iteration of the EQ program focused on teaching students spatial ability skills through paper-folding origami and engineering technical drawing activities.

Participants in the EQ program identified that an advantage of conducting the program online was that they were able to participate in the program from any physical location. Virtual programs can offer accessibility to students who may not have the means to travel to an on-site program that is at a distance from their present location. In addition, the online EQ program allowed students to have more flexibility in terms of how and when they completed the activities. Virtual programs allow students to complete asynchronous activities on their own time, allowing them to have flexibility in their schedules for other activities, work, or personal obligations.

In contrast, the program participants highlighted several disadvantages to conducting the EQ experience online. Participants indicated that it was difficult to receive help on some of the tactile aspects of the activities, such as knowing if their folded shape was correct, due to the virtual format of the program. In addition, participants mentioned that they sometimes had difficulty following along with some of the instructions that were given during the synchronous instructional program sessions. It may be worthwhile when developing STEM activities for BLV populations to give deep thought to how instructions are delivered and how they may be interpreted by students.

Educators should consider the option of offering virtual, online programs to engage and encourage participation from BLV students in STEM areas. The EQ program offered by the NFB was largely successful due to the structuring of the synchronous and asynchronous instruction and the kit of tactile materials that was provided to participants. These potential methods for overcoming areas of difficulty provide considerations for educators as they develop online programming for BLV populations.

Future work

This work will inform the development of future offerings of the EQ program at the NFB. The program may continue to be offered in-person or with additional online offerings. The latter may prove particularly useful in a crisis situation, similar to the COVID-19 pandemic, where there is still a desire to provide STEM education opportunities to BLV participants. This work can provide insights to other educators about the potential for virtual engineering educational experiences for BLV youth.

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